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NAVAL POSTGRADUATE SCHOOL
Monterey, California

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THESIS

A COMPARATIVE ANALYSIS OF A
CV HELICOPTER AND A JVX TILT-ROTOR AIRCRAFT
IN AN AIRCRAFT CARRIER BASED ASW ROLE

by

Robert L. Wilde

March 1985

Thesis Advisor: Dan C. Boger

DTIC FILE COPY

85 06 24 071

unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A Comparative Analysis of a CV Helicopter and a JVX Tilt-Rotor Aircraft In an Aircraft Carrier Based ASW Role		5. TYPE OF REPORT & PERIOD COVERED Masters Thesis March 1985
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Robert L. Wilde		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943		12. REPORT DATE March 1985
		13. NUMBER OF PAGES 133
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

(cont.)

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

~~ASW, Pouncer, JVX, CV Helicopter, SH-60F~~ Time On-Station; Search and Rescue; Flight Deck; Detection Probability; Helicopter In-Flight Refueling; Tilt-Rotor, and Dipping Sonar.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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S/N 0102-LF-014-6601

unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(cont)

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to 1473

S/N 0102-LF-014-6601

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A Comparative Analysis of a CV Helicopter and a JVX Tilt-Rotor Aircraft in an Aircraft Carrier Based ASW Role

by

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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

This thesis analyzes the environmental compatibility and the potential performance capabilities of two proposed types of vertical flight capable aircraft in an aircraft carrier Anti-Submarine role. The aircraft compared are the CV helicopter (SH-60F) and an ASW variant of the Joint Services Advanced Vertical Lift (JVX) tilt-rotor aircraft. This thesis compares their adaptability and relative expected mission effectiveness by analyzing their physical dimensions and characteristics and their projected flight performance parameters. Their expected performance in a specific scenario, an ASW pouncer mission employing active dipping sonar, is analyzed using a simulation model.

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I. INTRODUCTION

A major threat to an aircraft carrier battle group (CVBG) is an attack by a submarine. A submarine may attack with either or both torpedos and cruise missiles, depending upon its configuration. While many outer layer defenses exist and are highly effective in countering approaching submarines, submarines may and sometimes do approach close enough to pose a cruise missile threat, and they may even penetrate close enough to pose a torpedo attack threat. The airborne deterrent closest to the high value unit is currently the SH-3H Sea King which is a carrier-based anti-submarine helicopter. The SH-3H is tasked with anti-submarine warfare (ASW) in the carrier inner zone. The carrier inner zone is normally considered to be the area within fifty nautical miles.

Passive acoustics is an ideal method of detecting submarines, as a submarine may be detected without being alerted. However, the effectiveness of passive acoustics is seriously degraded in conditions of high ambient noise levels. The noise level in the water is increased by surface shipping traffic, and is particularly high in the area of an aircraft carrier battle group. Active dipping sonar, deployed by a hover capable aircraft has proven to be an extremely effective and reliable sensor in this

environment. This sensor enables an aircraft to search for, detect, localize, and quickly attack an enemy submarine.

Variants of the SH-3 have been in active service in carrier battle groups for over two decades, and have undergone numerous airframe and mission equipment modifications and improvements, including an onboard sonobuoy information processing capability. In addition to sonobuoys and dipping sonar, its ASW mission suite includes a magnetic anomoly detection (MAD) system and two MK-46 torpedos. While the SH-3H is a potent weapons system which can bring a variety of sensors and weapons to bear against an enemy submarine, the reduced availability of airframes due to attrition and the age of the aircraft has resulted in increased maintenance requirements and reduced mission reliability.

Because of the limited useful life remaining for the SH-3H Sea King, a replacement or follow-on aircraft is needed. A dipping-sonar-equipped version of the Sikorsky-built SH-60B Sea Hawk, currently in service in the Helicopter Anti-Submarine Light (HSL) community has been chosen as the replacement aircraft. It is anticipated that this CV helicopter will be designated the SH-60F.

Another aircraft, an ASW configured version of the Joint Services Advanced Vertical Lift (JVX) tilt-rotor aircraft, currently being developed jointly by the Bell and

Boeing Corporations for potential Marine Corps applications, has been proposed as a possible candidate for the carrier ASW mission. The tilt-rotor configuration of the JVX enables it to enjoy many of the characteristics of both helicopters and airplanes. It can take off and land either vertically or with a short roll with the prop-rotors tilted slightly forward. Taking off with a short roll allows the JVX to increase its maximum gross takeoff weight, enabling it to carry more fuel and thus improve its on station time and range. Once in flight, the prop-rotors can be tilted full forward and the aircraft can accelerate to approximately 275 knots. The maximum forward airspeed of the SH-60 is 180 knots.

Because of its unique vertical flight capability, the current carrier based helicopter has been routinely tasked with other missions as well as ASW. These secondary but critical missions include search and rescue, utility, and logistic support. It is an excellent platform for these missions because of its compatibility for landing or vertical flight operations and refueling with the majority of ships in the fleet.

Since the aircraft carrier outer layer ASW defenses such as the land based P-3C Orion maritime patrol aircraft, the S-3 Viking carrier based long range ASW aircraft, and ASW designated surface ships are utilized to detect submarines as far away from the carrier as possible, the carrier-based

helicopter with its rapid localization and attack capability is frequently utilized in a reactionary or pouncer mode. The dipping sonar equipped aircraft may respond to contacts generated by remote sources either from an airborne or an on-deck five minute alert status. Once the dipping sonar aircraft arrives on station, the platform which initially gained and reported a contact may be relieved and freed to search other areas.

This thesis investigates and compares the feasibility and expected effectiveness of the CV helicopter and the JVX in the carrier ASW environment, and specifically in a pouncer role. In order to compare these two distinct aircraft designs, their physical and flight performance characteristics are analyzed to determine their adaptability and relative expected performance for the projected operating environment. The aircraft characteristics and factors which are considered crucial for a vertical flight capable aircraft in the aircraft carrier ASW environment are speed, on-station time, carrier flight deck compatibility, compatibility with ships other than aircraft carriers, and feasibility for secondary missions. These elements are compared in Chapter II.

A model which simulates an ASW pouncer mission is constructed and executed for both aircraft types. The purpose of the model is to evaluate the significance of the

speed differential between the aircraft with respect to detection probability. Both one aircraft searching and two aircraft searching scenarios are modeled. The model and results are described in Chapter III. Conclusions and recommendations for further study are contained in Chapter IV.

II. COMPARISON OF THE AIRCRAFT IN THE PROJECTED OPERATING ENVIRONMENT

For an aircraft to be an acceptable and productive component of an aircraft carrier air wing, it must be compatible in the carrier operating environment and be able to perform its designated mission. In order to compare the CV helicopter and the JVX, several mission areas and aircraft characteristics are investigated and analyzed. The factors which are considered of primary interest are compatibility in the aircraft carrier flight deck environment, compatibility with ships other than aircraft carriers, aircraft time on-station, and the aircrafts' potential for the secondary mission of Search and Rescue (SAR).

A. AIRCRAFT CARRIER FLIGHT DECK ENVIRONMENT

1. Deck Spotting

For an aircraft to be a feasible component of an aircraft carrier airwing it must be compatible with the carrier flight deck. A crucial factor of flight deck compatibility is the quantity of space which the aircraft occupies both while taking off and landing, and while stowed. The size of the flight deck is a limiting constraint in the number of aircraft which can be deployed. All aircraft which routinely embark in aircraft carriers

are configured with blade or wing fold systems so that they will take up less space while not operating. Both the CV helicopter and the JVX are equipped with fold systems.

The two aircraft differ considerably with respect to size, both in the operating or spread configuration and in the folded configuration. The dimensions of each aircraft and their corresponding square footage appear in Figure 2-1. The dimensions of the current carrier ASW helicopter, the SH-3H Sea King are also included for purposes of comparison. All dimensions represent the largest sections of the aircraft. The square footage is obtained by multiplying the aircraft's length by its width. This is essentially the area of a rectangle drawn around each aircraft at it widest and longest points.

With both aircraft folded, the ratio of the square footage of the JVX to the CV helicopter is 2.25. The ratio of the area occupied by the JVX to the area occupied by the current carrier helicopter is 1.28. The ratio of the area occupied by the CV helicopter to the current carrier helicopter is 0.57, representing a significant decrease.

With the aircraft in the spread or operating configuration, the differences are not as great. The ratio of the area of the JVX to the CV helicopter is 1.39 and to the current carrier helicopter is 1.07. The ratio of the area occupied by the CV helicopter to the SH-3H is 0.77.

Folded Configuration

	CV Helicopter	JVX	SH-3H
Length	40.92	57.33	47.25
Width	10.70	17.20	16.33
Height	13.25	17.65	16.17
Area Folded (square feet)	437.84	986.08	771.59

$\frac{\text{JVX Area}}{\text{CV Helicopter Area}} = 2.25$ $\frac{\text{JVX Area}}{\text{SH-3H Area}} = 1.28$

Spread (operating) Configuration

Length	64.83	57.33	72.89
Width	53.67	84.50	62.00
Height	17.00	21.60	17.17
Area Operating	3479.43	4844.39	4519.18

$\frac{\text{JVX Area}}{\text{CV Helicopter}} = 1.39$ $\frac{\text{JVX Area}}{\text{SH-3H Area}} = 1.07$

Figure 2-1 Aircraft Dimensions
(units in feet)

When aircraft are positioned on the flight deck in the most compact way to maximize the number of aircraft which can be deployed, the shapes of the aircraft are considered. Aircraft can be parked in such a way that they are closer to each other than the boundary of a rectangle drawn at the greatest length and width of the aircraft. The square footage calculations above are for purposes of comparison only. The factor used to determine the effective space occupied by an aircraft on a carrier flight deck is its contribution to the carrier's deck multiple, or the aircraft's spot factor. It is a means of determining how many aircraft can be placed in an area of given size with optimal positioning. The A-7 Corsair is used as a reference and has a spot factor of 1.0. The spot factors of all embarked aircraft are aggregated and this numerical value is applied to the density of the particular aircraft carrier and a deck multiple is derived. This deck multiple determines the quantity and mix of aircraft which can be deployed on an aircraft carrier. The allowable deck multiple varies between aircraft carriers. The SH-3H has a spot factor of 0.8. The CV helicopter will have a spot factor of 0.60, and although the spot factor of the JVX is not yet determined, it is estimated to be approximately 1.30. These spot factors indicate that with respect to required deck space, the CV helicopter would be an improvement over the SH-3H and the JVX would contribute more

to carrier deck multiple than the current carrier helicopter. The spot factor of the JVX is approximately twice that of the CV helicopter.

2. Wind Limitations

An important factor which affects flight deck compatibility is aircraft wind limitations for taking off and landing. The JVX has a major advantage over the CV helicopter in this respect. A conventional helicopter, which is configured with a single main rotor and a single tail rotor, must take off and land into the wind. This is particularly critical while operating under conditions of high gross weights, high ambient temperatures, and high density altitudes. This restriction frequently requires that the aircraft carrier adjust its course and speed to place the relative flight deck winds within a prescribed envelope of direction and magnitude. When the aircraft carrier cannot maneuver, either for safety reasons or for a need to maintain a track, the launch of a helicopter may be delayed, or the helicopter may have to be repositioned on the deck. The counter-rotating prop-rotors of the JVX enable it to enjoy significantly less stringent wind limitations. The relative wind usually must be within forty-five degrees either side of the nose for a conventional helicopter. The relative wind for the JVX could probably extend out to at least ninety degrees either

side of the nose. These direction envelopes are dependent upon the magnitude of the wind vector.

3. Safety

One of the major safety considerations associated with the flight deck of an aircraft carrier is the danger of ground crew personnel inadvertently encountering propeller or rotor blades. The close proximity of operating aircraft and the numerous evolutions which occur simultaneously on a carrier flight deck subject ground crew personnel to many hazards. The tail rotor of a conventional helicopter posess a threat while it is in motion. The JVX does not have a tail rotor and therefore would not pose as great a threat to ground crewmembers. The main rotor systems of the CV helicopter and the JVX are high enough above the ground that they will not endanger ground crewmembers under normal conditions. The main rotor system of the CV helicopter may droop down to approximately 7.5 feet above the ground in front of the aircraft. The plane of each rotor system of the JVX is approximately twenty-one feet above the ground with the rotors turning. Extreme wind gusts may cause the main rotor blades of a conventional helicopter to dip down far enough as to endanger ground crew personnel. The rigidity and length of the JVX's blades would prevent them from dipping down far enough to be dangerous.

B. COMPATIBILITY WITH SHIPS OTHER THAN AIRCRAFT CARRIERS

The vertical flight capability of both aircraft types enable them to operate from and with numerous ship types in addition to aircraft carriers. This capability enhances their operational effectiveness and increases their margin of safety as there are more emergency landing sites available. Additionally, it provides more options in the area of command and control. If an aircraft carrier's flight deck is unavailable for landing or refueling due to other operations or a flight deck emergency, the vertical flight capable aircraft can refuel aboard or conduct Helicopter In-Flight Refueling (HIFR) operations with ships other than aircraft carriers. This option also facilitates temporary stationing of the inner zone ASW aircraft on escort ships to suit the tactical situation. Of paramount benefit is the potential lengthening of on-station time by the elimination of the need to return to the aircraft carrier to refuel.

1. Landing Compatibility

The factors which determine an aircraft's ability to land on a surface ship are its size, weight, and rotor diameter. The size of the landing area along with superstructure and obstacle placement and weight limitations of the host ship also dictate which types of aircraft can land. Currently the SH-3H Sea King can land on most U.S. fleet ships of deck size down to and including DD-963

Spruance class destroyers. The CV helicopter will be required to be compatible for take-off, landing, and stationing on all ships for which the SH-3H is currently compatible. Also it will be required to be compatible with all CV-41 and subsequent aircraft carriers, as well as all LAMPS MK III capable ships. It will be required to perform these functions on the FFG and CG ship types on which the SH-3H cannot land or can land with restrictions. The JVX aircraft is projected to be able to land on most ship types. Because of its much larger size, for obstacle clearance the JVX will face directly forward in its final landing position. Conventional helicopters land at a forty-five degree angle to the ship's heading. The JVX in this environment has an advantage of being less restricted by wind limitations because of its twin counter-rotating prop-rotors. The CV helicopter with a single main rotor and tail rotor configuration is restricted to landing within a prescribed wind envelope which generally requires maneuvering of the host ship. A disadvantage of the direct stern landing by the JVX is a reduced waveoff capability in the event of a single or dual engine failure on final approach or in close proximity to the ship. This type of approach will also place the aircraft in a flight regime where sections of the prop-rotor system will be in ground effect and other sections will be out of ground effect.

Theoretical aerodynamic principles infer that this dissymmetry of lift may result in control problems in some aircraft types, however flight tests of the XV-15, a tilt-rotor predecessor to the JVX have not indicated any control problems in this environment. While this type of landing allows the JVX to fit on most ship decks with adequate obstacle clearance, its much larger weight precludes its landing on several ship types due to their inadequate deck strengths. A landing weight above 32,000 pounds and a vertical take off weight above 41,000 pounds is beyond the capacity of the FFG-7, AOE-1, AE-26, and AFS-1 ship classes.

2. In-Flight Refueling Capability

While landing to refuel is the preferred method, when landing is not possible due to aircraft or ship size or if high sea states or wind conditions render landing a dangerous alternative, the SH-3H can refuel in flight from virtually all but a few ships in the fleet. Ships are generally ready to conduct HIFR operations on relatively short notice and usually within twenty minutes. These options and capabilities are routinely exploited.

The evolution of refueling a hovering aircraft from a surface ship is routine in nature and does not employ any sophisticated equipment. The aircraft descends to approximately fifteen feet over the deck and lowers a hoist onto which crewmembers on the ship attach a fuel line. Aircrew members in turn raise the fuel line and nozzle and

connect it to the aircraft's fuel cell input port located within the aircraft. Once the connection is made the aircraft slides horozontally clear of the ship and descends to a position approximately level with the flight deck to optimize the pumping conditions. The fuel line on the ship is handled manually by deck hands.

An inherent problem with this procedure is that the aircraft remains airborne in a high fuel consumption flight regime. This increases the time necessary to obtain the desired quantity of fuel, as fuel is being consumed simultaneously with refueling. If the host ship is unable to pump fuel at a rate significantly above the aircraft's consumption rate the evolution can be long or perhaps even fruitless. The rate at which ships can transfer fuel depends on the type and condition of their pumping equipment, and this varies from ship to ship. Generally the fuel pump rate is approximately 30 gallons per minute for most ship types.

Since the refueling aircraft is unable to contribute to the tactical situation and the HIFR procedure is fatiguing to both the aircrew and ship deck personnel, as short an evolution as possible is desired. The time required to HIFR as a function of net hours of fuel received for both aircraft types is displayed in Figure 2-2. The methodology for these calculations is as follows. The time

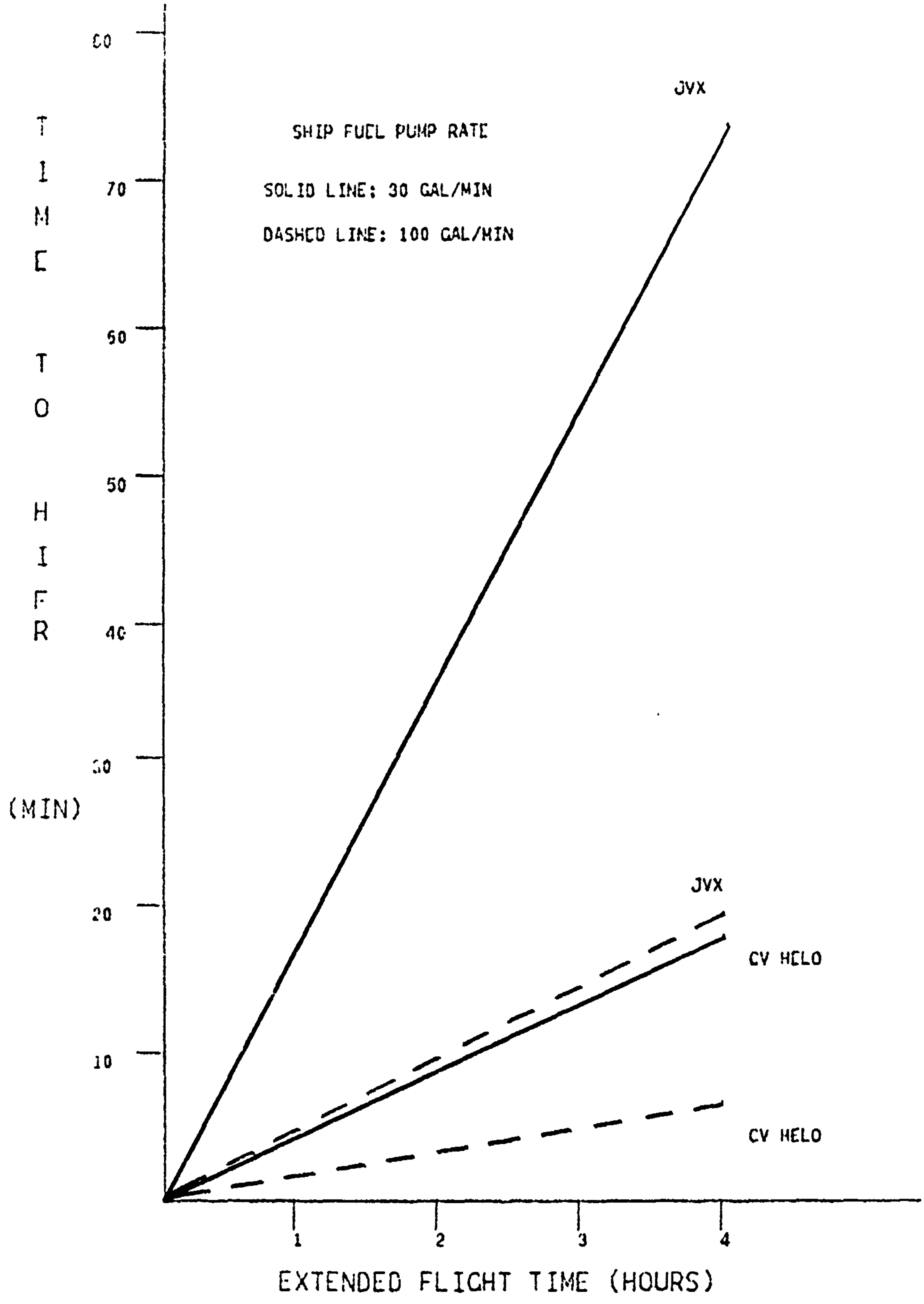


Figure 2-2 Time Required to HIFR

required in the HIFR position to obtain one hour of cruise speed fuel is equal to the amount of fuel required for one hour of flight at cruise speed divided by the net rate at which fuel is taken aboard. The net rate at which fuel is taken aboard is equal to the ship's pumping rate minus the rate at which the aircraft consumes fuel while hovering in the HIFR position. The calculations were performed using the following parameters with appropriate unit conversions. JP-5 aircraft fuel weighs 6.8 pounds per gallon. The CV helicopter consumes fuel at cruise speed and in a hover at the rates of 800 pounds per hour and 1100 pounds per hour respectively. The JVX consumes fuel at cruise speed and in a hover at the rates of 2700 pounds per hour and 3400 pounds per hour respectively. These consumption rates are for standard atmospheric conditions at sea level.

This illustration indicates that the JVX would have to remain in the HIFR position for approximately eighteen minutes for each additional hour of fuel obtained. HIFR times in excess of ten minutes for each additional hour of fuel obtained is considered unreasonable by current fleet standards and negates the advantage of the HIFR option. In order for the JVX HIFR procedure to be feasible the ship pumps would have to be upgraded. A pump rate of approximately ninety-five gallons per minute would be necessary for the JVX's HIFR time to be comparable to the CV helicopter's HIFR time at the current pumping rate of

approximately thirty gallons per minute. Because of the relatively high speed of the JVX it may be more prudent for it to return to the aircraft carrier to refuel if a landing capable ship was not available, or if the ship's fuel pumping rate was insufficient. At a distance of fifty nautical miles, the JVX could transit to the aircraft carrier in approximately twelve minutes at its maximum speed of 275 knots. However a rapid turnaround is unlikely on an aircraft carrier if other flight operations are being conducted. The CV helicopter's HIFR refueling system will be required to be able to receive fuel at pump rates of up to one hundred gallons per minute. Figure 2-2 also depicts the same relationships between the aircraft in the event that ship pumps are upgraded to pump at one hundred gallons per minute. While the JVX would still have to remain in the HIFR position about three times as long as the CV helicopter, the time required for each additional hour of fuel obtained is less by a factor greater than four than the time required at a thirty gallons per minute pump rate. A period of between four and five minutes for each hour of fuel obtained is very reasonable, and makes the HIFR option feasible and beneficial.

C. ON-STATION TIME

The time that an aircraft can remain on-station impacts heavily on many considerations in aircraft carrier battle

group tactical and logistical planning. The length of a cycle in aircraft carrier normal peacetime cyclic time operation, that is the time between scheduled launches, is primarily driven by the on-station times of the embarked tactical aircraft. The length of a cycle for currently configured airwings is one hour and forty-five minutes. The recovery of airborne aircraft immediately follows the launch of the next cycle aircraft. Current carrier ASW aircraft, the S-3A Viking and the SH-3H Sea King, have sufficient on-station times to enable them to remain airborne for two cycles which alleviates flight deck congestion. Tactical effectiveness increases with on-station time in an ASW environment. The ASW mission often requires that large areas be covered. On-station time is most crucial during the prosecution phase of an ASW problem. If an aircraft must leave station before a relieving aircraft arrives, the submarine could be allowed to escape further detection. On-station time is also an important factor in a Search and Rescue scenario, particularly if a large area must be searched.

An aircraft's on-station time is primarily dependent upon the quantity of fuel it can carry, the rate at which fuel is consumed, and the distance to station. The nature of the mission, which dictates flight profiles, also influences the time available on-station, as fuel

consumption rates vary with flight regimes. With vertical flight capable aircraft, hovering is a complex phenomenon, which is achieved through the interaction of many opposing aerodynamic forces. This results in high power requirements and reduced efficiency.

In order to compare the JVX and the CV helicopter with respect to potential on-station time, a scenario was developed. This scenario is an ASW mission where the aircraft launches from an aircraft carrier with a full fuel load, and proceeds to an ASW datum at its respective cruise speed. Once on-station, the aircraft conducts an ASW search by deploying a dipping sonar from a hovering position. If no detection is made in a search position, the aircraft retrieves the dipping sonar and transits to the next position of a systematic s pattern. Upon expiration of the aircraft's available on- on time, it returns to the aircraft carrier at cruise speed and lands.

With the intent of evaluating these two aircraft types with respect to potential on-station time, and in light of the search technique, it is considered that fifty percent of the time on-station will be spent hovering and fifty percent in forward flight at normal cruise speed. These proportions are generally accepted standards and are applied in aircraft requirement specifications.

Since many of the projected parameters of the JVX are based on prelimimary designs and experimental data involving

different organizations, there is a degree of variation. Estimates of the quantity of useful fuel which can be carried internally in the JVX vary from 10,920 pounds to 12,200 pounds. The JVX is also projected to be able to carry fuel externally at the expense of external loads such as torpedos. With two sponsor stations mounted, it is possible to carry two torpedos and one 400 gallon fuel tank. This 400 gallon fuel tank corresponds to an increase of 2720 pounds of fuel or approximately one hour of fuel at cruise speed. The average hover fuel consumption rate is projected to be 3400 pounds per hour with the current design. Fuel consumption at cruise speed is also a function of aircraft weight and decreases as aircraft weight decreases during a mission as fuel is consumed. The average cruise fuel consumption rate is projected to be at 2700 pounds per hour.

The factors which effect on-station time for the CV helicopter are not as variable as with the JVX, as it is a derivative of a thoroughly flight-tested aircraft. The dipping sonar version of the SH-60B is basically the same aircraft with alterations to its airframe and avionics. There are no changes with respect to its power-plant or rotor system configurations. The fuel capacity of the CV helicopter is 4000 pounds. Its hover cruise fuel consumption is 1100 pounds per hour and its average cruise fuel consumption is 800 pounds per hour.

Because of the variablility of the projected fuel parameters of the JVX, on-station times were evaluated for four variations of its fuel capacity and consumption rates, along with one case for the CV helicopter, for distances to station out to 150 nautical miles. This is depicted in Figure 2-3. Four cases of the JVX parameters were evaluated to facilitate a graphical sensitivity analysis. That is, to determine how important certain parameters are to on-station time. In all four cases of the JVX parameters analyzed, the average cruise fuel consumption rate is fixed at 2700 pounds per hour. This is the least variable of the projected aircraft characteristics.

Aircraft fuel consumption rates, both while hovering and in cruise flight, are dependent upon aircraft power requirements. These power requirements are influenced by environmental conditions such as wind and temperature, and aircraft conditions such as weight and flight profile. The most critical factor is aircraft weight. As an aircraft becomes lighter during the course of the flight, its power requirements, and subsequently its fuel consumption rates decrease. For the purpose of the comparisons illustrated in Figure 2-3, the fuel consumption rates are considered to be average rates over the duration of a mission. The description of the case parameters follows.

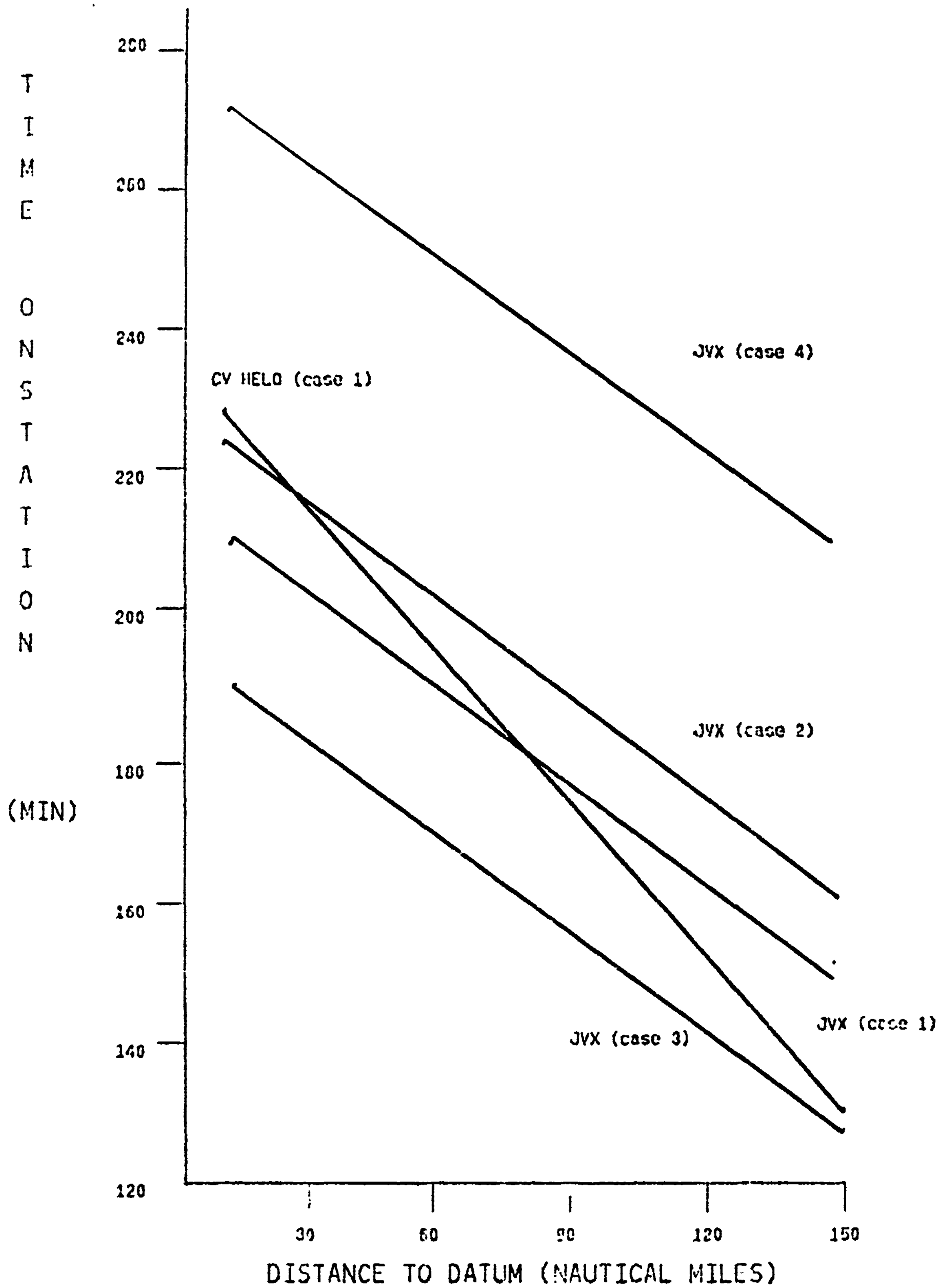


Figure 2-3 On-Station Time

JVX

Case 1.	Fuel Capacity	12000	pounds
	Hover Fuel Consumption Rate	3400	pounds per hour
	Cruise Fuel Consumption Rate	2700	pounds per hour
Case 2	Fuel Capacity	12000	pounds
	Hover Fuel Consumption Rate	3100	pounds per hour
	Cruise Fuel Consumption Rate	2700	pounds per hour
Case 3	Fuel Capacity	10950	pounds
	Hover Fuel Consumption Rate	3400	pounds per hour
	Cruise Fuel Consumption Rate	2700	pounds per hour
Case 4	Fuel Capacity	14920	pounds
	Hover Fuel Consumption Rate	3400	pounds per hour
	Cruise Fuel Consumption Rate	2700	pounds per hour

CV Helicopter

Case 4	Fuel Capacity	4000	pounds
	Hover Fuel Consumption Rate	1100	pounds per hour
	Cruise Fuel Consumption Rate	800	pounds per hour

The methodology for calculating these on-station times is as follows. The time on-station is determined by the quantity of fuel available on-station divided by the average fuel consumption rate while on-station. Since it is assumed that the time on-station will be divided evenly between

hovering and at cruise speed, the average fuel consumption rate on-station is the average of the hovering and cruise consumption rates. The fuel available on-station is the full capacity fuel load less the quantity used enroute to datum and the quantity used enroute back to the carrier at the end of the mission. In addition, a required reserve quantity of fuel was deducted from the fuel available on-station. Naval aviation regulations require that aircraft arrive at their destinations with a reserve fuel quantity of that necessary for twenty minutes of flight at a speed for maximum range, or ten percent of total fuel capacity, which ever is greater. With both the JVX and the CV helicopter, the higher quantity corresponds to the twenty minute requirement. For the JVX it is 900 pounds, and it is 266 pounds for the CV helicopter. The quantity of fuel used enroute is obtained from the time enroute multiplied by the cruise fuel consumption rate. The time enroute is determined by how long it takes the aircraft to transition to cruise speed after a vertical take off and how long it takes to travel the distance to datum less the distance covered during the speed transition. The JVX takes approximately fifteen seconds to accelerate to its cruise speed of 250 knots, and the CV helicopter takes approximately twenty seconds to accelerate to its cruise speed of 150 knots. During transition the speed changes are assumed to be linear.

Several assumptions are inherent in this scenario.

1. The distance which the aircraft must travel enroute to station, and on the return trip back to the aircraft carrier, are the same. This would be the case where there is no net carrier movement, and the aircraft ends his search at the initial datum.

2. No detections are made during the search phase which might alter the proportions of time spent in a hover and at cruise speed.

3. Fuel used on deck during starting is not considered, and all fuel is useable.

4. Wind conditions do not impact upon effective speeds and enroute times.

Figure 2-3 indicates that for case 1 each has an advantage over the other at different ranges. At approximately seventy-five miles to datum they have equal available on-station times. At a range of ten miles the CV helicopter has approximately a fifteen minute advantage, and at 150 miles the JVX has approximately a twenty minute advantage. The slope of the lines indicate that the advantage of the JVX over the CV helicopter would increase as distance to datum increases beyond 75 miles. Current aircraft carrier ASW doctrine defines the inner zone as a circle around the carrier with a radius of fifty miles. While this is not a steadfast boundary, beyond which the inner zone aircraft does not penetrate, it is generally accepted tactical guidance. As the inner circle is currently defined, the CV helicopter has an advantage in on-station time. It should be noted that between ranges of 10 to 130 nautical miles,

the largest deviation is fifteen minutes, which is not a large difference. It should also be noted that for comparable on-station times, the JVX consumes approximately three times as much fuel as the CV helicopter.

Case 2 represents a fuel consumption rate of 3100 pounds per hour for the JVX. This is approximately a ten percent decrease in the hover fuel consumption rate of Case 1 with the same fuel capacity. In this case the JVX and the CV helicopter also have advantages over each other, but the CV helicopter's advantage only extends out to approximately twenty miles. At one hundred miles to datum the difference in time on-station is approximately sixteen minutes. This illustrates that a ten percent reduction in the JVX's fuel consumption rate with a fuel capacity of 12,000 pounds, would significantly improve its on-station time relative to the CV helicopter.

Case 3 represents the JVX with it lowest projected fuel capacity and a hover fuel consumption rate of 3400 pounds per hour. Under these conditions the CV helicopter has an advantage in on-station time at all ranges out to 150 nautical miles with the greatest difference of approximately thirty-six minutes at ten miles to datum. Both aircraft have approximately the same on-station time at 150 miles to datum.

Case 4 depicts the JVX with a 12,200 pound internal fuel capacity and one external tank containing 400 gallons (2720

pounds JP-5), and a hover fuel consumption rate of 3400 pounds per hour. In this configuration the JVX has a considerable advantage in on-station time over the CV helicopter at all distances to datum out to 150 nautical miles. The difference is about forty-two minutes at ten miles to datum and about seventy-seven, minutes at 150 miles to datum. This illustrates that this increase in fuel capacity, with the same hover fuel consumption rate as Case 1, significantly improves the JVX's on-station time.

D. SEARCH AND RESCUE

Search and Rescue (SAR) is a mission of paramount importance to an aircraft carrier battle group for numerous reasons. A proven SAR capability strongly influences the morale of personnel whose jobs on the flight deck expose them to hazards such as jet blast and high winds, conditions which can result in man-overboard situations. A strong airborne SAR capability also impacts positively on the morale of tactical aircrews whose missions may take them great distances from the aircraft carrier. In a hostile environment, a SAR capability may mean the difference between rescue and capture for aircrews.

Search and Rescue has never been the primary mission of any generic aircraft carrier airwing aircraft. The offensive mission of an aircraft carrier and the limited space available for aircraft restricts the embarked aircraft

to those which contribute to the primary missions of projected airpower and battle group defense. Subsequently, SAR is designated as a secondary mission. Currently the SH-3H helicopter is the primary airborne SAR vehicle for aircraft battle groups. Any follow-on aircraft with a hover capability will likely also be tasked with SAR as a secondary mission.

Generally Search and Rescue situations occur in close proximity to the aircraft carrier, resulting from man-overboards or downed aircraft during launch and recovery operations. The use of the aircraft carrier's or another ship's motor whale boat as a recovery vehicle is a time tested and typically effective rescue method. However it is not useful if search is required and is only effective at short ranges. In addition, high sea states may prohibit its use. An airborne SAR vehicle can usually respond quicker and is effective at much greater ranges. Response time often determines a life or death outcome in the case of a distressed or injured potential survivor. In many areas of the world low water temperatures may rapidly induce hypothermia which necessitates a quick rescue.

The potential success of a SAR attempt depends on many factors and conditions, and rarely are the conditions identical for any two SAR situations. Daylight under visual meterological conditions (VMC) with adequate ceiling and

visibility is the most advantageous situation for a SAR mission. This environment simplifies both the search and rescue phases, and may facilitate a mission of relatively short duration. Under these conditions, a rescue aircraft may search a wide area by flying at an altitude of at least five hundred feet above ground level (AGL), which provides a large visual horizon, and an airspeed determined by pilot judgement. Speeds between eighty and one hundred knots would be appropriate when searching for a lone potential survivor. Factors such as sun position and glare may influence the search altitude, airspeed and pattern orientation. During periods of reduced visibility or at night, a much lower altitude is necessary to distinguish objects in the water. Current SAR doctrine recommends an altitude of 110 feet AGL, and a groundspeed of sixty knots for searches during instrument meterological conditions (IMC). [Ref. 1] Other factors, independent of the capabilities of the rescue aircraft and aircrew, which strongly influence the outcome of a SAR attempt are the actions and equipment used by a potential survivor. The proper use of reflective material signaling devices, and locater beacons can simplify the scenario and increase the probability of rescue.

The basic differences in flight characteristics between the CV helicopter and the JVX make them very different with respect to SAR potential. The JVX with its speed advantage

will have the ability to arrive at a search datum more quickly. This advantage is minor at short distances, but becomes pronounced as the distance to search datum increases. The maximum speed for the JVX is 275 knots and the maximum speed for the CV helicopter is 180 knots.

The time required, measured from initial notification, for each aircraft type to arrive on-station at distances out to 150 nautical miles is illustrated in Figure 2-4. These relationships reflect the situation where the aircraft are in a five minute alert posture and respond to a SAR report by taking off, transitioning to forward flight and proceeding to the search datum at maximum speed. For the purpose of this comparison, it is assumed that both aircraft types are able to maintain their maximum speeds throughout the transit to datum. Additionally, wind factors are not considered which could influence effective ground speeds, and it is assumed that navigational errors do not exist, allowing each aircraft type to proceed directly to datum. The purpose of this scenario is to determine potential differences between the aircraft. During normal flight operations the inner zone ASW aircraft is usually airborne and within close range of the aircraft carrier and would be able to react more quickly to a SAR event. The SAR aircraft would be in a fifteen or thirty minute alert posture during periods of no flight operations. The method used to

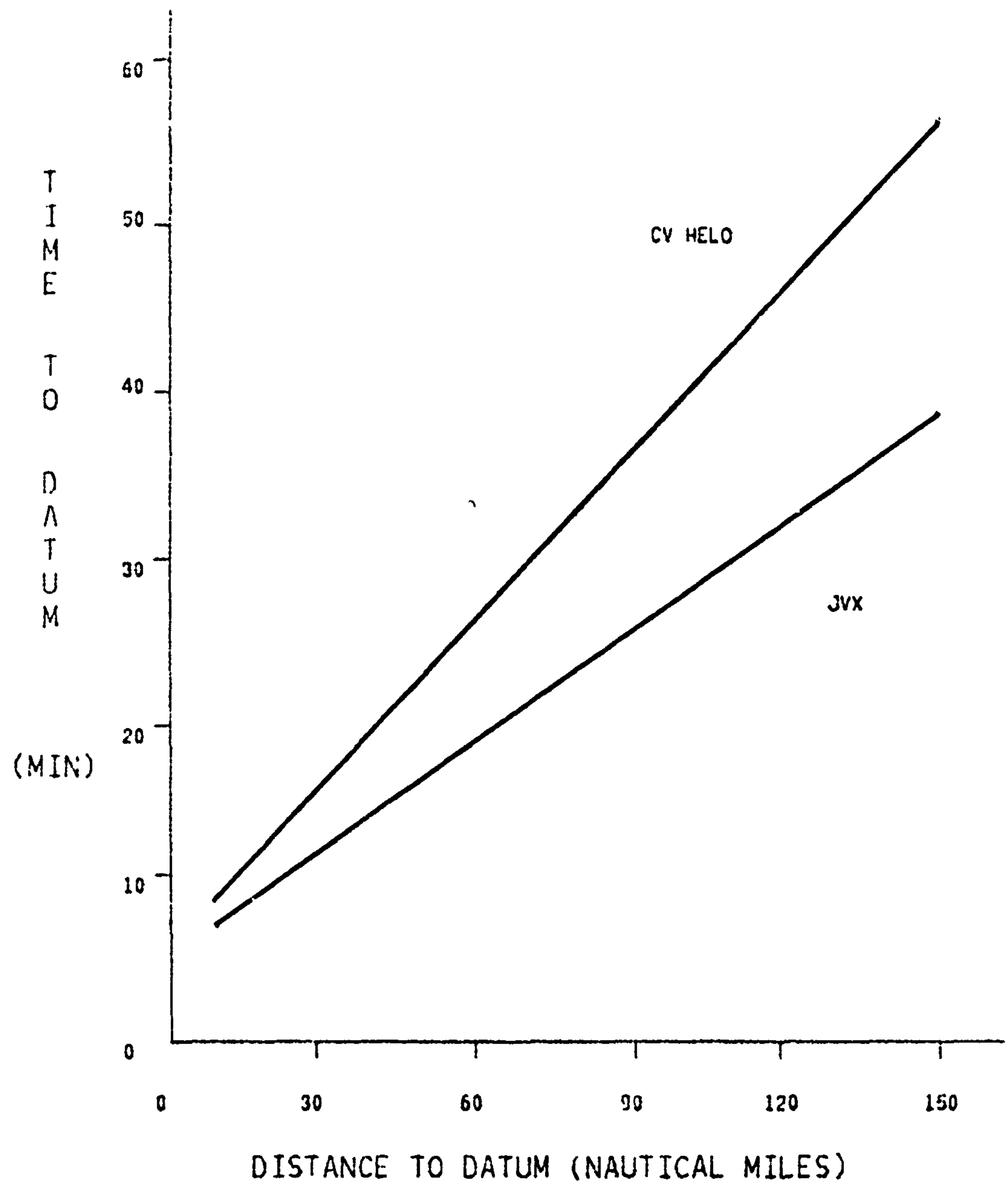


Figure 2-4 SAR Time to Datum

determine the time to arrive at datum is as follows. The total time is equal to the sum of the off deck time, the time for the forward flight transition and the time required to travel the distance to datum less the distance covered during forward flight transition. As an example, the time for the CV helicopter to arrive at a search datum at twenty minutes is calculated as follows. The CV helicopter takes off five minutes after notification and travels one-half of a mile during its twenty second transition to maximum speed. This assumes a linear increase in speed during the transition. At its maximum speed, it takes 6.5 minutes to travel the remaining 19.5 miles to datum, for a total time of 11.83 minutes.

At a range of ten nautical miles there is approximately a one minute advantage for the JVX, but at ranges beyond seventy nautical miles and out to one hundred and fifty nautical miles, the JVX takes approximately seventy percent of the time that the CV helicopter takes to arrive at a search datum. During routine peacetime operations, the majority of SAR situations occur in close proximity to the carrier battle group, usually within twenty nautical miles, so the speed advantage of the JVX would be of little consequence. During hostile operations when tactical aircraft are involved with air strikes at great distances from the aircraft carrier, inland or over water, this speed advantage would be beneficial. An evaluation of the JVX

...craft for the Combat Search and Rescue (CSAR) mission conducted by the Center for Naval Analyses (CNA) concludes that a much lower capture rate would result for a downed airmen with the JVX than with a conventional helicopter in cases of deep penetration of enemy territory. This is entirely credited to the speed advantage of the JVX. This study also concludes that for scenarios similiar to those experienced during the Vietnam War when most aircraft were downed in highly populated coastal regions close to CSAR stations, the superior speed of the JVX would do little to improve mission effectiveness. [Ref. 2] This study does not consider aircraft survivability. The higher speed of the JVX would make it less susceptible to damage from ground fire than the CV helicopter.

An inner zone ASW aircraft will not be configured for a CSAR role. This configuration entails armor plating, firepower, and specialized search devices. This mission equipment would require major airframe modification and redesign, and is not compatible with an ASW designed aircraft. Currently there are specially equipped aircraft and trained aircrews for the CSAR mission and non-CSAR designated aircraft would only attempt a rescue in a sanitized area when resistance is highly unlikely. For these reasons, a long range SAR capability for an aircraft carrier battle group is not considered of prime importance.

As discussed previously, once a search aircraft arrives at datum, the optimal search tactic is determined by the environmental conditions. With an established recommended airspeed and altitude during instrument conditions, there would be no major difference between the aircraft in this respect. During visual meteorologicly conditions, when the optimal search altitude and speed are influenced by the ceiling and visibility, the JVX would be able to cover a much greater area in a given time period. For the CV helicopter, search parameters of above five hundred feet AGL altitude would be appropriate. The JVX would utilize the same altitude for a given situation, but would search at speeds up to two hundred knots. It should be emphasized that these parameters depend upon many factors and are considered benchmarks. A particularly important consideration is the size and visual contrast of the object being search for. Under these assumptions, the JVX would be able to search a geographical area roughly twice that of a CV helicopter in a fixed amount of time. This increased coverage would be very beneficial in situations with low confidence search datums.

The rescue phase of the SAR mission, like the search phase varies greatly with respect to meteorological conditions. During daylight with favorable environmental factors, the rescue aircraft approaches the victim(s) under manual pilot control. During a night rescue, an approach

technique is performed which utilizes an automatic control system. The pilot flys a windline rescue pattern which positions the aircraft downwind of the survivor and engages the automatic control system which flys the aircraft from a gate position of 150 feet AGL and sixty knots to a hover close to the survivor. This method is considerably less expedient than the manual method, but is necessary due to the lack of visual references for the pilot and the high susceptibility to vert in this flight regime. A major difference between the :V helicopter and the JVX in this phase of the mission is aircraft wind limitations. The conventional helicopter must approach the survivor and hover into the wind. The JVX with its counter-rotating prop-rotors is much less restricted. This aerodynamic dissimilarity would not be significant during day rescues when a manual approach is executed. However in a night rescue scenario, the lack of wind limitations for the JVX eliminates the need to execute a windline rescue pattern, which would result in less pilot workload and a reduction in rescue time. During a night rescue attempt, the JVX would still have to execute an automatically controlled approach, but without concern for wind orientation, and could reach the survivor up to two minutes sooner. This time difference could be crucial to a downed pilot who is injured, or experiencing parachute entanglement.

A factor which must be considered when evaluating the feasibility of an aircraft for a SAR mission is the magnitude of rotor downwash. This is the velocity and downward mass flow of the air below the aircraft caused by the rotor systems. If it is too great, it may render an aircraft non-SAR capable, as the airflow may cause enough turbulence in the water that a SAR attempt would be fruitless. The downwash of the CV helicopter will not be a limiting factor, and the aircraft is required to be SAR capable. The JVX with its much more powerful engines and prop-rotors is expected to have a stronger downwash. Because of the location of the prop-rotors on the wingtips, the area directly below the fuselage is expected to be relatively calm. The JVX could perform a rescue by remaining directly over the victim during pickup. This would not be difficult during day rescues, but could be during night rescues when hover stability is much more demanding due to the lack of discernable visual references.

E. SUMMARY

There are many differences between these two aircraft types with respect to their potential feasibility and compatability in the aircraft carrier operating environment. Both aircraft have advantages over the other in several mission areas and operating characterisitics. This chapter has investigated those areas which are considered to be of

principle interest. Figure 2-5 contains an abbreviated description of the findings in these comparisons.

	CV HELO	JVX
FLIGHT DECK ENVIRONMENT		
Deck Spotting	requires less space spread and folded CV spot factor 0.6	requires more space spread and folded CV spot factor 1.3
Wind Limitations	more restricted (+ or - 45 degrees for take-off)	less restricted (+ or - 90 degrees for take-off)
Safety	rotor system droop tail rotor	high rotor system no tail rotor
SHIPBOARD COMPATIBILITY (other than CV's)		
Landing	more landing ships available	less landing ships available (weight/ size limitations
In-Flight Refueling (time required)	superior at ship fuel pump rates of 30 Gal/Min	comparable at ship fuel pump rates of 100 Gal/Min
ON-STATION TIME (ASW mission)	advantage at less than 75 miles to datum	advantage at greater than 75 miles to datum
SEARCH AND RESCUE		
Time to reach datum	disadvantages at all distances to datum	advantages at all distances to datum
Rescue Capability	equal	equal (procedure modified due to rotor downwash)

Figure 2-5 Summary of Aircraft Comparisons

III. COMPARISON OF THE AIRCRAFT IN A SIMULATED ASW MISSION

The aircraft are compared with respect to their potential performance in a simulated ASW pouncer mission. In a pouncer role an aircraft responds to a contact reported by another source. The purpose of the model is explained, along with a description of the scenarios, model methodology, and model assumptions. This is followed by model validation and a discussion of the results.

A. PURPOSE OF THE MODEL.

The purpose of the model is to provide insight into how important the speed differential between the aircraft is and at what ranges to datum it is significant. There is no appreciable difference between the JVX and the CV helicopter with respect to on-station time under their Case 1 conditions of a normal ASW search mission where the aircraft proceed to their search stations or datums at cruise speed and utilize the dipping sonar as the primary sensor. This similarity applies out to ranges of approximately one hundred nautical miles. Under the base case parameters for both aircraft, the difference is at most twenty minutes and both aircraft have approximately a 3.1 hour on-station time at seventy-five miles to search datum. With these results established, the question arises as to what is the

fundamental difference between the aircraft in potential ASW mission effectiveness. The major difference is speed.

The effectiveness of an attack on a submarine by an air launched torpedo is highly dependent upon how close to the submarine the torpedo enters the water and its guidance instructions. A hover-capable aircraft with a dipping sonar is an ideal platform for this mission as it can be placed in an optimal launch position relatively quickly once a detection is made. In light of these factors, scenarios are modeled in which the inner zone ASW aircraft acts as a pouncer, reacting to a datum generated by a remote source.

As measures of effectiveness the model predicts the overall probability of detection, the conditional probability of detection within a specified time period given that a detection occurs, and the conditional probability of detection by a specified look position given that a detection occurs. The remote source which generates a datum could be a ship or an aircraft such as an S-3A Viking or a P-3C Orion. For the purpose of this comparison the remote source which reports the contact plays no further role in the scenario, and the intentions of the submarine are unknown.

Both one aircraft and two aircraft scenarios are modeled for each aircraft type. That is, a scenario was run for the cases of one CV helicopter, one JVX, two CV helicopters, and two JVX's. The model was constructed and executed in

FORTRAN and run on the Naval Postgraduate School's IBM 3033 mainframe computer. It employs the Monte Carlo simulation technique and is a combination of critical event and several time step executive processes. The scenarios were each run separately for each aircraft type incorporating their individual projected flight characteristics. Each scenario was replicated 1000 times. A description of the model construction and the program listing is contained in Appendix A.

Many tactical factors can be analyzed with this model, such as the optimal separation between search positions and the optimal amount of time to remain in each search position. The combination of tactical parameters which yielded the best results in each situation was determined and utilized for comparing the best potential performance of each aircraft type. While the model could be refined to suit other purposes, the basic intent is to compare the relative expected performance of the aircraft. The model considers only the active dipping sonar sensor and does not investigate the ramifications of sonobuoy or magnetic anomoly detection (MAD) tactics.

The model is constructed to also measure the ability of an aircraft to maintain contact with the submarine once it has been detected. This is quantified by the ability to redetect the submarine in subsequent search positions using

various tactics. This feature was included in the preliminary stages of programming, but is not useful as a measure of effectiveness with respect to detection probability or for comparing the aircraft and is not included as output.

B. DESCRIPTION OF THE MODEL

1. <u>Description of the Scenarios</u>

a. One Aircraft Searching

In this scenario the inner zone ASW aircraft is on the deck of an aircraft carrier in a five minute alert posture. Its mission is to respond to a submarine contact generated by a remote source. When the datum is established, the aircraft launches from the aircraft in five minutes and proceeds to the datum at its maximum speed. Upon reaching datum the aircraft commences an ASW search employing active dipping sonar. The aircraft positions itself at datum, establishes a hover, and lowers its dipping sonar into the water. If no contact is made with the submarine, it retrieves its dipping sonar and transits to the next search position. The time required for the aircraft to travel between search positions is a function of acceleration and deceleration times, airspeed limitations, and the distance to be traveled. The aircraft follows a north-oriented expanding square search pattern [Figure 3-1]. It remains in each discrete search position

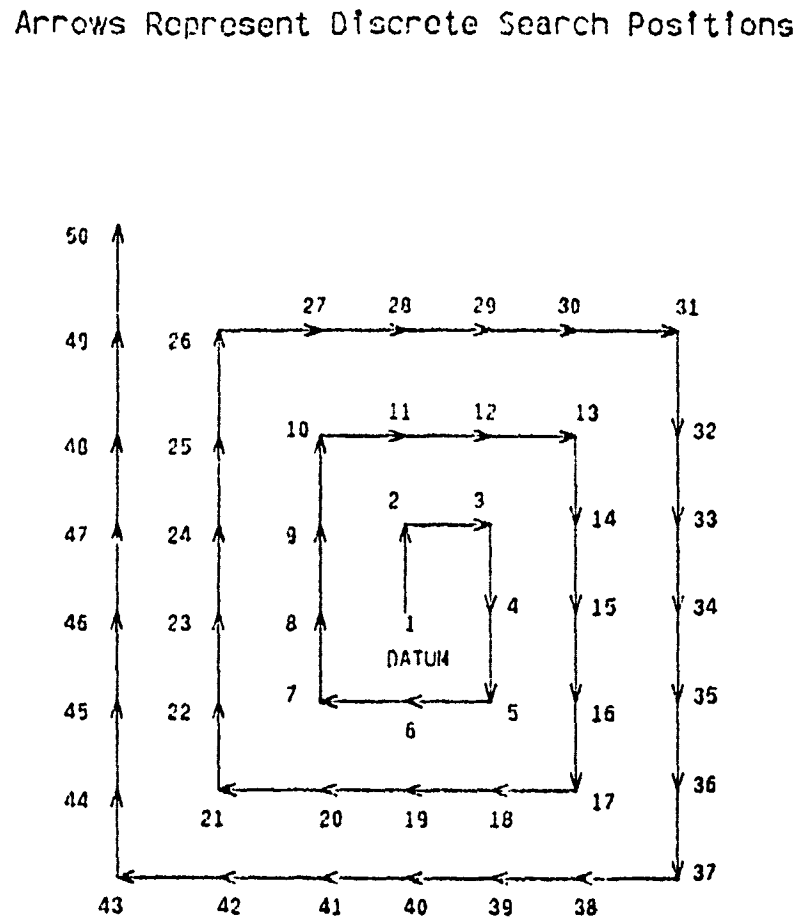


Figure 3-1 Expanding Square Search With One Aircraft

for a predetermined amount of time. While in a sonar hover, discrete looks occur every ten seconds. This corresponds to 'pings' with an active dipping sonar. Search positions are either three, four, or five nautical miles apart depending upon the optimal tactic for the time late.

The aircraft follows its systematic search pattern until the expiration of its available time on station, or until it detects the submarine. The available time on station is dependent upon fuel capacities, fuel consumption rates, flight regimes, and distance to datum.

Five cases of submarine speeds are simulated. In one case the submarine's speeds is random with a Uniform distribution between speeds of five and twenty knots. In the other four cases, the submarine's speed is fixed at five, ten, fifteen, and twenty knots. In all cases the submarine's course is random with a Uniform distribution between 0 and 359 degrees. These assumptions reflect the unknown intentions of the submarine.

There are three possible events which can occur in each search position or sonar hover which consists of a series of discrete detection opportunities.

First, when an aircraft begins a sonar hover the submarine is within TSR. In this event the distance between the aircraft and submarine is calculated and a probability of detection is determined based on a Normal distribution of the TSR. A Uniform [0,1] random number is compared to this

probability of detection and a detection or a non-detection is recorded. As long as the submarine is within TSR and has not been detected, its position is updated every ten seconds based on its course and speed, and search looks occur every ten seconds until the expiration of the aircraft's allotted time per search position. There would be thirteen 'pings' or detection opportunities in a two minute sonar hover if a detection did not occur.

Second, when an aircraft begins a sonar hover the submarine is not within the TSR but will be within range during the sonar hover. In this event the submarine's position is updated based on its course and speed in thirty second intervals to determine if it has moved within TSR. If the submarine has moved within TSR the probability of detection and a detection or a non-detection event are determined in the same manner as in event one.

Third, when the aircraft begins a sonar hover, the submarine is not within TSR and will not be within TSR during the search cycle. In this event the submarine's position is updated based on its course and speed, and the length of the aircraft's sonar hover search time. The aircraft proceeds to its next position in the expanding square pattern.

b. Two Aircraft Searching

The two aircraft scenario is identical to the one aircraft scenario with respect to search technique,

submarine actions, and detection methodology. The aircraft launch from the aircraft carrier simultaneously and proceed to the datum area. One aircraft initially positions itself at datum and follows the same search pattern as in the one aircraft scenario. The second aircraft initially positions itself in a position which is offset from the first aircraft's position by one-half of the designated distance between search positions to the south and to the west. The second aircraft follows a south-oriented expanding square search pattern with each reposition direction opposite that of the first aircraft. This approximates a spiral search pattern where the aircraft expand outward from datum in a symmetric manner. [Figure 3-2].

In this scenario the aircraft remain in each search position an equal amount of time and reposition simultaneously. The detection opportunities of each aircraft are independent of the other aircraft, and detection probabilities are dependent only on the distance between each aircraft's sonar and the submarine.

2. Model Methodology and Assumptions

a. Maximum Dip Time and Distance Between Search Positions

The models were run for combinations of dip times ranging from two to five minutes and distances between dips ranging from two to five nautical miles in the single aircraft expanding square search pattern for all distances

Arrows Represent Discrete Search Positions

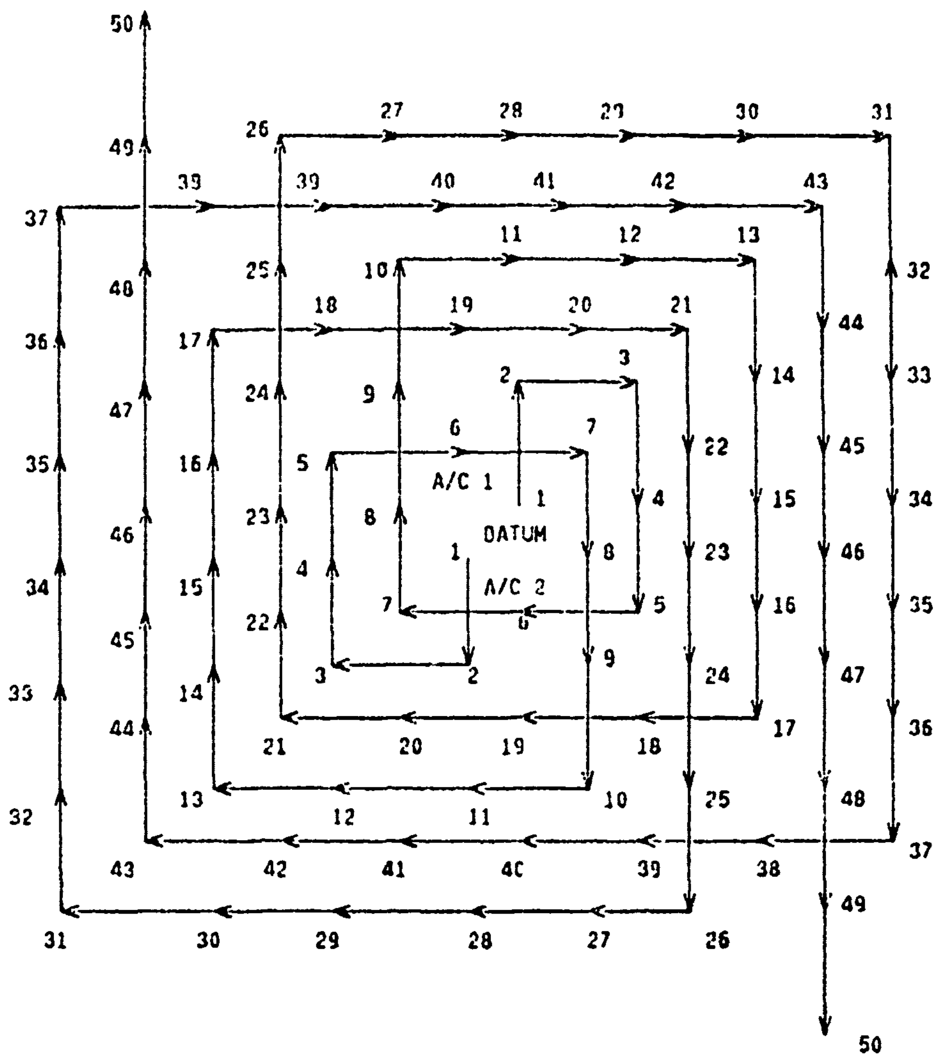


Figure 3-2 Expanding Square Search With Two Aircraft

to datum for both aircraft types. For the purpose of determining a general trend in the tactical combinations which yielded the highest detection probabilities, 500 replications were conducted for several of the scenarios prior to the actual simulation runs.

In these preliminary model runs, for all cases the least amount of time spent in each search position yielded the best detection probabilities. This can be interpreted as a detection will occur early in a search position or it will not occur at all. This correlates to the unlikelihood that the submarine's track would bring it within the aircraft's TSR in a discrete search position if it was not already within the aircraft's TSR at the beginning of the dip. Consideration was given to evaluating each aircraft's performance using shorter sonar hover position times than two minutes, but two minutes is considered to be the practical minimum in current fleet tactics. Establishing and maintaining a hover is both mentally and physically taxing to an aircrew. It must be remembered that safety of flight while operating close to the water, as well as the tactical employment of sensors and weapons are factors with which the aircraft commander is concerned. Search position times of less than two minutes would probably lead to better results, but two minutes is considered reasonable with respect to pilot workload and was used in all actual model simulations.

The optimal distance between search positions in the expanding square search pattern varies with distance to datum. Generally, as distance to datum and time late increase, greater separations between search positions lead to the best results. This observation was also made during the preliminary model runs.

b. Frequency of Detection Opportunities While in a Sonar Hover

While in a sonar hover, if the submarine is within TSR the distance between the aircraft and the submarine is calculated and a detection or a non-detection is determined every ten seconds. This 'ping' rate considers the time involved in transmitting the active sonar signal, waiting for a return signal, and the sonar operator's decision process of determining whether a contact is present or not. Depending upon environmental conditions and the sonar operator's experience, more or less frequent transmission rates may occur. In this model ten seconds is assumed to be the average rate.

The probability of detection on each discrete detection opportunity in a search position is assumed to be independent of all other discrete detection opportunities. Each is a probabilistic occurrence and is influenced only by the current range between the aircraft's sonar and the submarine. This is directly related to the assumption that

the depth of the sonar and the submarine, and the aspect of the submarine do not influence detection probabilities.

c. Expanding Square Search Pattern; (One Aircraft Searching)

In this scenario it is important to realize that the intentions of the submarine are not known. If it were known that the submarine intended to approach the aircraft carrier, a search pattern which concentrated on the area between the submarine's reported position and the aircraft carrier would be appropriate. In these models the submarine is on a random course which may or may not approach the aircraft carrier. An expanding square pattern approximates a spiral pattern which is germane under these circumstances. Variations of spiral search patterns are routinely used in this situation in current fleet tactics. Since the submarine's course is random the orientation of the search pattern is not crucial. A north-oriented search pattern was used to simplify programming considerations.

d. Expanding Square Search Pattern (Two Aircraft Searching)

In the scenario of two aircraft searching for the submarine, each aircraft also follows an expanding square pattern. The intentions of the submarine are also unknown in this scenario and the area about datum can be searched approximately twice as quickly than in one aircraft scenario. Some overlap in the area covered may occur depending upon the distance between search positions.

e. Detection

The detection event in this model is determined using a fitted normal probability distribution. The greatest range at which it is possitle to detect the submarine is the tactical sonar range. In the case of active dipping sonar this is usually direct path sound propagation. TSR varies with environmental factors, particularly temperature, pressure and salinity. In this model TSR is fixed at 4000 yards. The mean detection range, μ, is one-half the tactical sonar range. That is, the probability of detecting the submarine at 2000 yards is 0.5. The standard deviation, σ, was determined so that the cumulative probability of detection within TSR was approximately one, and its value must generate reasonable probabilities for the ASW dipping sonar based on fleet experience. A standard deviation of 800 yards was used.

The detection probability distribution function is

$$F_X(x) = \Phi\left(\frac{x-\mu}{\sigma}\right) \quad ,$$

where X is a random variable and is defined as the detection range. The probability of detection at a detection range x is

$$1 - F_X(x)$$

The model calculates the actual range, r, to the submarine from the dipping sonar. The probability of detection at this range r is equal to the probability that the detection

range is greater than the calculated range, and this is equal to $1-F_X(r)$.

$$P(Det) = P(x > r) = 1 - F_X(r)$$

Figure 3-3 displays the lateral range curve based on a normal distribution of definite ranges. The probability of detection in a search position is assumed to be circular normal, allowing the cross-section of the distribution to be symmetric and used at all bearings. With this detection distribution, the probability of detection at 0 yards is 0.5, and the probability of detection at 4000 yards is approximately 0.0. These models consider only the lateral range to the target, and not target aspect or submarine depth.

The probability of detection during a search is approximated by the number of detections made divided by the number of attempts. The probability of detection by a certain time is approximated by the number of detections made by that time divided by the number of attempts where a detection has occurred. The probability of detection by a certain search position number is approximated by the number of detections which occurred by that search position number divided by the number of attempts where a detection occurred. The probability of detection on the first 'ping' of the first search position is approximated by the number of detections made on the first 'ping' of the first search position divided by the number of attempts.

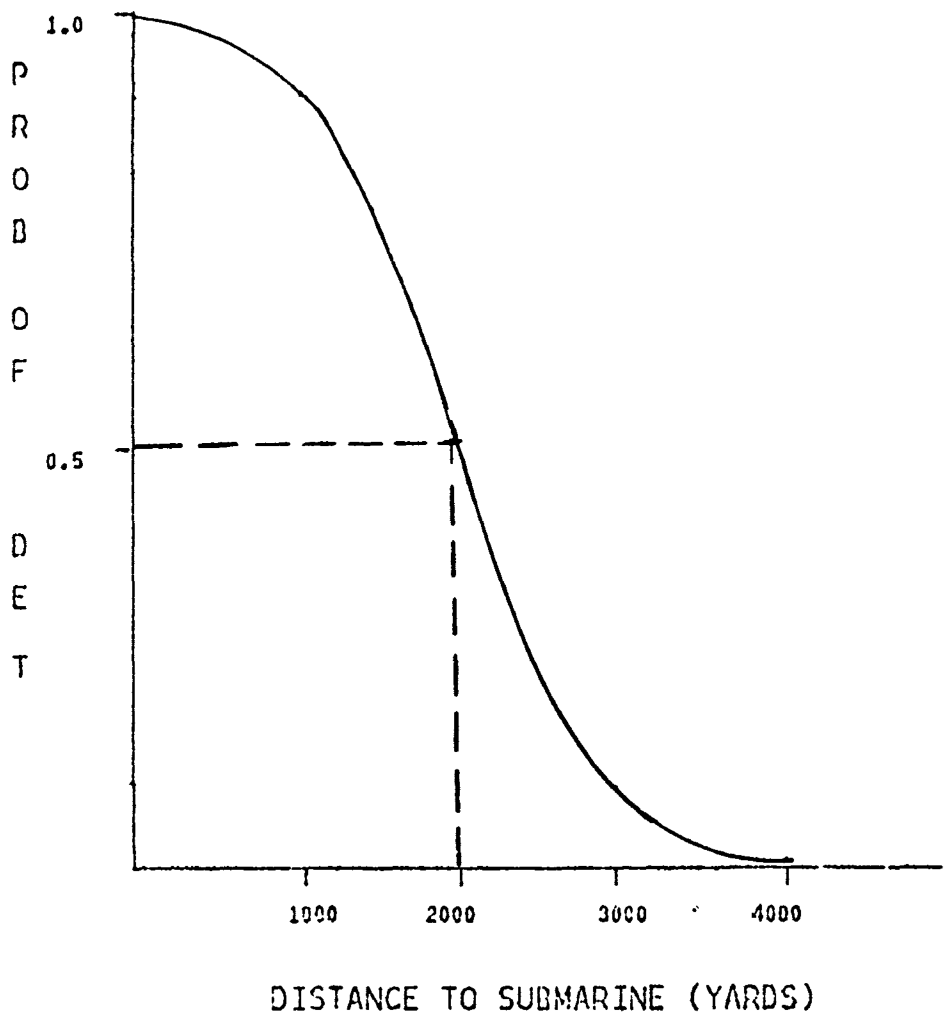


Figure 3-3 Lateral Range Curve

It is assumed that the use of active dipping sonar by the searching aircraft does not influence the actions of the submarine. The principles of underwater acoustics state that sound waves propagate much greater distances than the distance at which it is possible for the transmitting source to receive a recognizable return signal. This means that a submarine could be alerted of the presence of a searching aircraft prior to the aircraft detecting the submarine. This could influence the submarine to alter its track before it is actually detected in an attempt to evade contact. Since the time that the searching aircraft remains in a search position is only two minutes, it is unlikely that the submarine would be able to locate the source of the sonar signal and determine if it could be detected, and would probably not initiate evasive maneuvers. In addition, there may also be other active sonars, probably from surface ships, operating in the area.

f. Aircraft Search Speed

This is the effective or average speed which an aircraft attains between search positions in the expanding square search pattern. It directly determines the amount of time required for the aircraft to transmit between search positions and is used to update the submarine's position. Aircraft search speed is calculated by the distance to be traveled divided by the time required between search positions. In this model the time between search positions

is the time which the aircraft takes to reposition from a sonar hover with the dipping sonar lowered to another sonar hover with the dipping sonar lowered. The method used to determine elapsed time between search positions follows.

Time between search positions = time to retrieve the sonar

+ time to transition to transit speed

+ time to travel the distance between search positions less the distance covered during transitions

+ time to transition to a sonar hover

+ time to lower the sonar

The time required to raise and lower the sonar transducer while in a sonar hover depends upon the depth at which the search is being conducted and the effective speed of the reeling machine. There are minor variations between reeling machines. This model does not consider submarine depth, and subsequently sonar position depth. For the purpose of evaluating the time between sonar hovers ten seconds is used for the time to retrieve the sonar and five seconds for the time to lower it for both aircraft types.

The current dipping sonar aircraft has a forward airspeed limitation of 100 knots while the sonar transducer is deployed. Between sonar hover positions the sonar transducer is raised to a trail position of about three to four feet below the aircraft. The sonar transducer is not

retrieved all the way to the seated position within the aircraft as this evolution may be time consuming. The forward flight limitation exists to prevent damage to the aircraft and the sonar transducer resulting from airflow induced oscillations of the transducer and cable. It is assumed that a follow-on dipping sonar aircraft will have the same limitation. If the aircraft were able to completely retrieve the sonar in a timely manner, they would be able to transit between search positions at higher speeds, however since the search positions are only two miles apart the difference in time would be insignificant. Therefore, the maximum attainable speed between search position is 100 knots in this model.

Transition time is the time required for the aircraft to accelerate to their transit speed of 100 knots and from 100 knots to a hover. The JVX takes seven seconds for this transition and the CV helicopter takes ten seconds for this transition. This difference in transition time is insignificant.

g. Time Enroute to Datum

The time it takes an aircraft to arrive at datum is a function of the distance to datum and the aircraft's flight characteristics. The time enroute to datum was calculated under the following assumptions.

1. Each aircraft performs a vertical take-off. Short roll take offs were not considered.

2. Each aircraft type launches five minutes after notification. This represents each aircraft in a five minute alert posture.

3. The JVX takes fifteen seconds to transition from and to the airplane and helicopter mode. This is the time required to rotate the prop-rotor system through its full movement. During this transition it accelerates or decelerates between 0 and 275 knots of forward airspeed.

4. The CV helicopter takes twenty seconds to accelerate and decelerate between the speeds of 0 and 180 knots.

5. Each aircraft requires twenty seconds upon arrival at datum to establish and position itself in its initial sonar hover.

6. Both aircraft require ten seconds to lower the sonar transducer.

7. The change in speed for both aircraft during speed transitions is assumed to be linear.

Time Enroute = time to launch (5 minutes)

+ time to transition to maximum forward airspeed (JVX 15 seconds, CV helicopter 20 seconds)

+ time to transit at maximum speed a distance equal to the distance to datum less the distance traveled during speed transitions.

+ time to transition from maximum speed to a hover

+ time to lower the sonar transducer

h. Distance to Datum

The scenarios were simulated for distances to datum out to one hundred nautical miles. While the current aircraft carrier ASW inner zone is defined to be fifty nautical miles, further ranges are of interest. Both the JVX and the CV helicopter have higher maximum cruise speeds

than the SH-3H. The capabilities and limitations of currently available assets drive tactical procedures. The SH-3H is most effective at ranges out to fifty nautical due to its speed and on-station time parameters. It is possible that the capabilities and limitations of the replacement aircraft for the SH-3H would lend credence to a reevaluation of ASW tactical doctrine and a redefinition of ASW zone boundaries.

C. MODEL VALIDATION AND CORROBORATION

Model validation and corrobation was accomplished by two methods, one being an inspection of the output for obvious inconsistencies or errors, and the other being more mathematically driven analysis. An examination of the model ouput for obvious inconsistencies will be discussed first.

Since the only difference in the aircraft characteristics of significance in this model are maximum transit speed and on-station time, it would be expected that the aircraft which can arrive at datum with the least time late would have greater success. The JVX with its superiorty in speed does in fact have at least the same or a greater probability of detection in all cases examined. It would also be expected that detection probabilities would decrease as the range to datum, and subsequently time late increases. This is indeed the case for both aircraft types at all variations of submarine speed.

In two aircraft scenario, a greater area around the datum is searched in the same amount of time as in the one aircraft scenario, and therefore the probability of detecting the submarine should be higher in the two aircraft scenario. While the quantitative improvement with two aircraft searching varies with submarine speed, the detection probabilities produced by the model are greater with two aircraft searching than with one aircraft searching in all cases simulated.

The aircraft have on-station time limitations which are determined by the distance to datum, aircraft speed, and fuel capacity and consumption rates. In all model runs, the time which the aircraft remain on-station is within the limitations of their on-station times.

Intuitively it would seem that an aircraft would have a higher probability of detecting a slow moving submarine than a fast moving submarine while following an expanding square search pattern. The model is consistent in this respect as the detection probabilities are high with slow moving submarines and decrease as submarine speeds increase.

An output from the model for each scenario is the probability of detecting the submarine on the first detection opportunity or 'ping' at the first search position of the expanding square search pattern. In the scenario of one aircraft searching, this probability can be determined analytically when the submarine's speed is fixed. When the

submarine's speed is fixed, its distance from datum when the searching aircraft arrives at datum can be determined and the analytic probability of detection calculated based upon the detection probability distribution used in the model. The distance the submarine has traveled when the aircraft arrives at datum is its speed multiplied by the aircraft's time enroute to datum. The resulting analytic probability of detection at this distance is calculated using the model's detection probability distribution.

The probabilities of detection on the first detection opportunity at the first search position derived analytically and those produced by the model for the search tactics which yielded the highest overall detection probabilities appear in Figure 3-4. These probabilities represent the situation where the submarine's speed is fixed at 5.0 knots. It should be noted that the search tactics of search position separation and search position time do not influence these results, and therefore, the simulated probability of detection on the first search opportunity should be similiar for all model runs where the submarine speed is fixed. This is indeed the case. The fact that they are not identical is attributed to variations in the order in which random numbers are generated. The analytical and simulated probabilities exhibited in Figure 3-4 are very close at all distances to datum for both aircraft carriers.

One CV Helo Searching Subspeed Fixed at 5.0 Knots

Distance to Datum	Aircraft Time enroute (minutes)	Submarine Distance From Datum When Aircraft Arrives (yds.)	Analytic P(Ping)	Model P(Ping)
10	9.17	1528.33	0.7224	0.7250
20	12.50	2083.33	0.4602	0.4560
30	15.83	2638.33	0.2119	0.2280
40	19.17	3195.00	0.0681	0.0600
50	22.50	3750.00	0.0143	0.0210
60	25.83	4305.00	0.0000	0.0000
70	29.17	4861.67	0.0000	0.0000
80	32.50	5416.67	0.0000	0.0000
90	35.83	5971.67	0.0000	0.0000
100	39.17	6528.33	0.0000	0.0000
	One JVX Searching Sub Speed 5.0 Knots			
10	7.93	1321.67	0.8023	0.7960
20	10.11	1685.00	0.6517	0.6700
30	12.30	2050.00	0.4900	0.4460
40	14.48	2413.33	0.3015	0.3180
50	16.66	2776.67	0.1660	0.1720
60	18.84	3140.00	0.0771	0.0860
70	21.02	3503.33	0.0300	0.0290
80	23.20	3866.67	0.0099	0.0100
90	25.39	4231.67	0.0000	0.0000
100	27.57	4595.00	0.0000	0.0000

Figure 3-4 Model Validation

With a five knot submarine, the time it takes the CV helicopter to arrive at datum makes it impossible for the aircraft to detect the submarine at the initial search position at ranges to datum of sixty nautical miles and beyond. The simulated probabilities are consistent in this respect. It is impossible for the JVX to initially detect the submarine at a range of ninety nautical miles and beyond. The simulated detection probabilities here are also consistent with those derived analytically.

D. Model Results

The model output which is used as the measure of effectiveness to compare the predicted performance of the CV helicopter and the JVX in each scenario is the overall probability of detection. Figures 3-5 through 3-9 display the results for the one and two aircraft scenarios for the five cases of submarine speeds. The information in these figures was extracted from the model output for all variations of input parameters. Appendix C contains a representative cross section of the model output for several cases. These tables also indicate the search position separation used and the mission time by which all detections occurred. The mission time begins when a remote sensor reports the datum. In each case the tactic of search position separation (three, four, or five nautical miles), which yielded the highest overall detection probability was

One Aircraft

Distance to Datum (Nautical Miles)	Optimal Search Position Separation (Nautical Miles)		Probability of Detection		Mission Time (Minutes)	
	CV Helo	JVX	CV Helo	JVX	CV Helo	JVX
10	3	4	.5440	.6010	40	70
20	4	4	.4020	.4970	100	70
30	4	4	.3190	.3940	170	80
40	4	4	.2500	.3470	160	160
50	5	4	.2100	.3140	140	170
60	5	4	.1850	.2500	130	170
70	4	4	.1410	.2340	160	160
80	5	4	.1500	.2030	140	160
90	5	5	.1190	.1150	140	130
100	5	5	.0990	.1650	150	140

Two Aircraft

10	3	3	.6970	.7620	50	50
20	4	4	.5810	.6630	100	90
30	4	4	.5120	.6100	160	160
40	4	4	.4510	.5610	150	160
50	4	4	.3570	.5140	150	160
60	5	4	.3280	.4550	130	170
70	5	4	.2990	.3930	130	160
80	4	4	.2370	.3830	110	160
90	5	4	.2200	.3000	130	110
100	5	4	.1970	.2950	130	50

Figure 3-5 Submarine Speed Uniformed (5.20) Knots

One Aircraft

Distance to Datum (Nautical Miles)	Optimal Search Position Separation (Nautical Miles)		Probability of Detection		Mission Time (Minutes)	
	CV Helo	JVX	CV Helo	JVX	CV Helo	JVX
10	3	3	1.0000	1.0000	20	10
20	3	3	1.0000	1.0000	140	20
30	3	3	.9950	1.0000	150	50
40	3	3	.9730	1.0000	150	50
50	3	3	.9100	.9940	160	150
60	3	3	.8700	.9630	160	150
70	3	3	.8150	.9350	140	150
80	4	3	.7620	.9170	130	150
90	4	3	.7490	.8960	130	160
100	4	3	.7480	.8370	130	90
Two Aircraft						
10	3	3	1.0000	1.0000	20	10
20	3	3	1.0000	1.0000	50	20
30	3	3	1.0000	1.0000	150	40
40	3	3	1.0000	1.0000	150	50
50	3	3	1.0000	1.0000	160	150
60	3	3	1.0000	1.0000	160	150
70	3	3	.9990	1.0000	140	150
80	3	3	.9910	.9990	110	150
90	3	3	.9700	1.0000	150	160
100	3	3	.9230	1.0000	150	100

Figure 3-6 Submarine Speed Fixed at 5.0 Knots

One Aircraft

Distance to Datum (Nautical Miles)	Optimal Search Position Separation (Nautical Miles)		Probability of Detection		Mission Time (Minutes)	
	CV Helo	JVX	CV Helo	JVX	CV Helo	JVX
10	3	3	.7140	.9010	40	50
20	3	3	.4740	.5980	40	30
30	4	3	.3990	.4510	80	40
40	5	4	.3510	.4160	90	80
50	5	4	.2910	.3710	90	70
60	5	4	.2310	.3310	80	70
70	5	5	.1840	.3120	80	90
80	5	5	.0990	.2780	50	80
90	5	5	.0460	.2490	50	80
100	5	5	.0280	.2040	60	80
Two Aircraft						
10	3	3	.9330	.9760	50	50
20	3	3	.8390	.8870	60	60
30	4	3	.7400	.8600	80	60
40	4	3	.6670	.7740	70	60
50	5	4	.6000	.7620	90	70
60	5	4	.5640	.7010	90	80
70	5	5	.4320	.6240	100	90
80	5	5	.3460	.5500	110	90
90	5	5	.2270	.6000	110	90
100	5	5	.1450	.5140	110	90

Figure 3-7 Submarine Speed Fixed at 10.0 Knots

One Aircraft (* no detections)

Distance to Datum (Nautical Miles)	Optimal Search Position Separation (Nautical Miles)		Probability of Detection		Mission Time (Minutes)	
	CV Helo	JVX	CV Helo	JVX	CV Helo	JVX
10	3	4	.2640	.2800	20	30
20	4	3	.2170	.2570	30	30
30	5	4	.1710	.2030	30	30
40	5	4	.1060	.1820	40	30
50	*	5	.0000	.1610	*	30
60	*	5	.0000	.1320	*	40
70	*	5	.0000	.0660	*	40
80	*	5	.0000	.0180	*	40
90	*	*	.0000	.0000	*	*
100	*	*	.0000	.0000	*	*

Two Aircraft

Distance to Datum (Nautical Miles)	CV Helo	JVX	CV Helo	JVX	CV Helo	JVX
10	4	3	.5350	.5630	40	30
20	5	4	.4370	.4750	40	40
30	5	4	.3180	.4110	40	40
40	5	5	.2260	.3700	40	40
50	4	5	.1340	.3230	40	40
60	5	5	.0930	.2630	50	40
70	5	4	.0920	.1680	50	40
80	5	4	.0540	.1390	50	40
90	5	4	.0230	.0970	50	40
100	*	5	.0000	.1020	*	50

Figure 3-8 Submarine Speed Fixed at 15.0 Knots

One Aircraft (* no detections)

Distance to Datum (Nautical Miles)	Optimal Search Position Separation (Nautical Miles)		Probability of Detection		Mission Time (Minutes)	
	CV Helo	JVX	CV Helo	JVX	CV Helo	JVX
10	5	4	.1740	.2120	30	20
20	5	5	.1250	.1690	30	30
30	5	5	.0010	.1360	30	30
40	*	5	.0000	.0290	*	30
50	*	*	.0000	.0000	*	*
60	*	*	.0000	.0000	*	*
70	*	*	.0000	.0000	*	*
80	*	*	.0000	.0000	*	*
90	*	*	.0000	.0000	*	*
100	*	*	.0000	.0000	*	*

Two Aircraft

10	4	4	.3810	.4160	30	20
20	5	5	.2800	.3480	30	30
30	4	5	.1230	.2830	30	30
40	5	5	.1140	.1670	40	30
50	5	4	.0580	.1160	40	30
60	*	5	.0000	.0900	*	40
70	*	5	.0000	.0940	*	40
80	*	5	.0000	.0390	*	40
90	*	5	.0000	.0070	*	40
100	*	*	.0000	.0000	*	*

Figure 3-9 Submarine Speed Fixed at 20.0 Knots

chosen and used for comparison. In situations where the detection probabilities were close between different search tactics, the case where ninety-five percent of the detections occurred in a shorter period of time and in a fewer number of search positions was chosen.

On-station time proved not to be a factor for either aircraft type in the ASW pouncer scenarios. In all cases the incremental increase in the number of detections decreases as time elapses. This means that once an initial threshold of time is reached when detections are possible, they occur relatively quickly, and the likelihood of detecting the submarine diminishes in later search positions. The initial time threshold time before which detections are impossible, is dependent upon distance to datum, aircraft speed and submarine speed.

The model results show that the time required for the searching aircraft to arrive at datum is a crucial factor in the success of an ASW pouncer mission. The JVX with its higher maximum speed arrives at datum sooner than the CV helicopter at all distances to datum, and subsequently has at least the same or a higher probability of detecting the submarine for all variations of submarine speed. This is true in both the one and two aircraft scenarios. The results also show that in all cases, detection probabilities are higher with two aircraft searching than with one aircraft searching. This is attributed to the greater datum

area coverage with two aircraft. The improvement in detection probabilities with two aircraft searching is most significant with higher submarine speeds.

In light of the model results which indicate that the probability of detection is a function of aircraft enroute speed, the magnitude of the difference in detection probabilities becomes of interest. It would be expected that the difference in this magnitude would increase as the distance to datum increases, since the time enroute difference becomes more pronounced. The detection probability differences with increasing distances to datum varies with submarine speed and the number of aircraft searching. There is no appreciable difference in overall detection probability between two aircraft when the submarine's speed is at the extreme of those analyzed.

1. <u>Submarine Speed Fixed At Five Knots [Figure 3-6]</u>

When the submarine's speed is fixed at 5.0 knots, both aircraft have extremely high probabilities of detection at ranges out to one hundred nautical miles. In the one aircraft scenario the JVX detects the submarine with certainty out to ranges of forty nautical miles and the CV helicopter detects with certainty out to approximately thirty nautical miles. Beyond the ranges where both aircraft detect with certainty, the difference in detection probabilities remains fairly constant with the JVX having

approximately a 0.10 advantage. While the overall detection probabilities do not differ significantly, the mission time required for all contacts is considerably less with the JVX at ranges out to forty miles. At a range of forty miles the JVX makes all its detections within fifty minutes, as compared to 150 minutes for the CV helicopter. With two aircraft searching, the JVX's detect the submarine with certainty at virtually all distances to datum out to one hundred nautical miles. The CV helicopters detect with certainty out to distances of sixty nautical miles and with probabilities of at least ninety-two percent out to one hundred nautical miles. At distances to datum out to forty miles, the JVX makes all its contacts in a considerably shorter period of time, and at fifty miles and beyond, there is no appreciable difference in mission time between the aircraft. These results indicate that the differential in speed between the aircraft is of little significance in detection probability against a slow moving submarine, but is an important factor in the mission time required.

2. Submarine Speed Fixed At Twenty Knots [Figure 3-9]

When the submarine's speed is fixed at twenty knots, there is also little difference in detection probabilities between the aircraft. In the one aircraft scenario the CV helicopter has essentially a zero probability of detection at distances to datum of thirty nautical miles and beyond. The JVX has a zero probability of detection at ranges of

fifty nautical miles and beyond. At ranges of thirty nautical miles and less both aircraft have approximately a twenty percent or less chance of detection. The only significant difference is at thirty miles where a single JVX has approximately a 0.14 detection probability and a CV helicopter has approximately a 0.001 detection probability. A statistical test of differences, which utilizes the facts that the probability of detection for both aircraft types are Bernoulli parameters, and the difference in the probabilities is approximately normal, was performed. The null hypothesis is that both aircraft types have the same probability of detection at thirty miles to datum. With a significance level, alpha, of 0.05, (the risk of rejecting the null hypothesis when it is true) the null hypothesis was rejected. Therefore, the difference in detection probabilities is significant.

In the two aircraft scenario the CV helicopter has a zero probability of detection at sixty miles and beyond, and the JVX has less than a ten percent probability of detection at ranges of sixty miles and beyond. Again the only significant difference between the aircraft occurs at thirty miles to datum where the JVX has a 0.28 detection probability and the CV helicopter has a 0.12 detection probability. Here, a test of the hypothesis that the probabilities are the same for both aircraft types also

concluded that they are not the same with a significance level of 0.05.

In both the one and two aircraft scenarios, there is no real difference between the aircraft in mission time, and detections all occur within forty minutes of the datum being generated. Against fast moving submarines, both aircraft either gain contact early into a mission or not at all.

3. Submarine Speed Distributed U(5,20) Knots [Figure 3-5]

When the speed of the submarine is unknown and is simulated as a random variable distributed uniformly between five and twenty knots, the JVX has a higher overall probability of detection at all ranges with both one and two aircraft searching. In the one aircraft scenario there is not a trend in the magnitude of the difference in detection probabilities as the range to datum increases, and the JVX generally has between a 0.05 and a 0.10 advantage in overall detection probability. In this case, a test of differences of the detection probabilities.for each aircraft type rejects the hypothesis that they are the same at all distances to datum except ninety miles. A significance level of 0.05 as utilized. At ninety miles to datum there is no difference between aircraft. At ten miles to datum the CV helicopter has an advantage in mission time and the JVX has an advantage at ranges of twenty and thirty miles. Beyond thirty miles there are no considerable differences in

mission time between the aircraft. With two aircraft searching the only significant differences between the aircraft occur at fifty and eighty nautical miles to datum. At fifty miles the JVX has approximately a 0.16 increase in detection probability with a similiar mission time. At eighty miles the JVX has a 0.15 increase in detection probabilities is less than or equal to 0.12 and there are no major variations in mission time.

4. Submarine Speed FIxed At Ten Knots [Figure 3-7]

When the submarine's speed is fixed at ten knots, the JVX has a considerable advantage over the CV helicopter at most ranges to datum. With one aircraft searching the difference between detection probabilities ranges between 0.10 and 0.20 for most distances to datum, and the magnitude of the differences tends to increase with distance to datum. For both aircraft types, the longest mission time is ninety minutes. With two aircraft searching the magnitude of the difference in detection probabilities also increases with distance to datum, and the largest difference is at ninety miles where the JVX has a 0.373 advantage. There is also little difference in mission time between the aircraft.

5. Submarine Speed Fixed At Fifteen Knots [Figure 3-8]

When the submarine's speed is fixed at fifteen knots, the JVX has an advantage at longer ranges to datum. In the one aircraft scenario, the CV helicopter has no chance of detecting the submarine at fifty miles and beyond,

and the JVX has little or no chance at seventy miles and beyond. At ranges where they both can detect the submarine, the JVX has a minor advantage. There are no significant differences in mission times between the aircraft with the longest time being forty minutes. With two aircraft searching, the JVX's advantage occurs at ranges of forty miles and beyond. At beyond forty and sixty miles to datum, the JVX has between a 0.14 and 0.19 advantage in detection probability. At eighty miles and beyond, the CV helicopter has little or no chance of detection and the JVX has approximately a ten percent chance of detection. The longest mission time with two aircraft searching is fifty minutes.

IV. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

A. CONCLUSIONS

There are differences in the expected compatibility and projected effectiveness between the CV helicopter and the JVX in all of the areas investigated in this thesis. The advantages of each aircraft are mixed. That is, each aircraft is better suited or has more potential effectiveness than the other in different areas. The physical and flight performance characteristics which distinguish the aircraft are size, weight, wind envelopes, fuel quantity and consumption rates, and speed.

The smaller size of the CV helicopter enables it to operate with and from more ship types. It also occupies less space on the aircraft carrier flight deck. The wind envelopes for take off, landing, and hovering are less restrictive for the JVX which simplifies the operating procedures of both the aircraft carrier and other surface ships.

For approximately equal on-station times for the two aircraft in a mission profile which consists of the time on-station being divided evenly between cruise flight and hovering, the JVX consumes roughly three times the quantity of fuel which the CV helicopter consumes. In addition, the relatively high fuel consumption rates of the JVX leads to

doubts concerning the feasibility of its performing the HIFR evolution with current ship fuel pumping rates of approximately thirty gallons per minute. If ship fuel pumping rates were upgraded to one hundred gallons per minute, the JVX would be well suited for this evolution.

The flight characteristic which most prominently distinguishes the aircraft is speed. While the CV helicopter's maximum speed of 180 knots represents a significant improvement over the current carrier based ASW helicopter's maximum speed of 120 knots, its maximum speed is ninety-five knots less than the JVX. This speed differential proved to be significant with respect to long range non-combat Search and Rescue potential and in an ASW pouncer mission.

In the ASW pouncer mission employing an expanding square search tactic, the magnitude of the differences in detection probabilities, credited to the speed difference between the aircraft, proved to be dependent upon the speed of the submarine. Generally, there is little difference in predicted performance between the aircraft when the submarine's course is unknown, but its speed is either slow or fast. When the submarine's speed is also unknown, but is equally likely to be any speed between five and twenty knots, the JVX consistently has at least the same or a greater chance of detecting the submarine than the CV

helicopter. The improvement in detection probability of the JVX over the CV helicopter tends to increase as the distance to the reported datum position increases. In addition to an increase in detection probabilities, the speed advantage of the JVX generally enables it to detect the submarine in a shorter period of time.

B. RECOMMENDATIONS FOR FURTHER STUDY

This thesis has investigated several operationally oriented areas in comparing these two types of aircraft. It is by no means exhaustive, as there are many other important factors which merit comparison. The maintainability and reliability of the aircraft and their systems, and the associated economic ramifications should be investigated. Both of these topics are critically important. Because helicopters have been in service for many years, there exists a vast amount of experience and expertise in helicopter maintenance. A tilt-rotor configured aircraft, while not a new concept, has not been proven in fleet service and there is no existing experience in its maintenance. A factor which would influence its flight deck compatibility and maintainability is the complexity of its wing/blade fold system. This factor merits specific concentration.

The scenarios which have been modeled for the purpose of comparing mission effectiveness are very specific. Other

ASW mission flight profiles, such as random area searches which employ other sensors in addition to dipping sonar should be investigated. In the ASW pouncer mission model, on-station time proved not to be a limiting constraint. In a random area search, it probably would be a determining factor with respect to area coverage and flight profile. This model analyzed only the search phase of the ASW mission. Further studies could expand this to include localization and weapon system considerations.

APPENDIX A.

MODEL CONSTRUCTION

A. INTRODUCTION.

The ASW pouncer mission model consists of a main program and five subroutines. All the program variables are declared as common to the main program and the subroutines. The methodology for the calculations performed throughout the model is documented in the program listing.

B. PROGRAM OUTLINE

Main Program:

The main program is used to set the input variables. It initializes the bookkeeping arrays and calls either the one aircraft searching subroutine or the two aircraft searching subroutine, depending upon the input parameters. The subroutines return the generated results and the main program outputs the results. The construction of the main program is illustrated with a flow chart.

Subroutine S1AC1:

This subroutine simulates the scenario of one aircraft searching for the submarine. It receives the input values and bookkeeping arrays from the main program and replicates the search procedure 1000 times at each distance to datum.

It returns the generated results to the main program to be output. This subroutine invokes subroutine SUBPOS to calculate the submarine position and subroutine GRIDS to establish the coordinates of the aircraft's search positions. The construction of this subroutine is illustrated with a flow chart.

Subroutine S1AC2:

This subroutine simulates the scenario of two aircraft searching for the submarine. It receives the input values and the initialized bookkeeping arrays from the main program and replicates the search procedure 1000 times at each distance to datum. It returns the generated results to the main program to be output. This subroutine invokes subroutine SUBPOS to calculate the submarine's position. It also invokes subroutine GRIDS to establish the coordinates of the first aircraft's search positions, and subroutine GRIDSS to establish the coordinates of the second aircraft's search positions. The methodology of this subroutine is identical to that used in the one aircraft searching subroutine. All procedures and calculations are performed in a similar manner, but are performed simultaneously and independently for each searching aircraft.

Subroutine SUBPOS:

This subroutine calculates the submarine's position based on its course, speed and previous position. Because

this function is frequently required in the scenarios, it was incorporated into a separate subroutine in the interest of minimizing source code lines. It is invoked by the S1AC1 and S1AC2 subroutines.

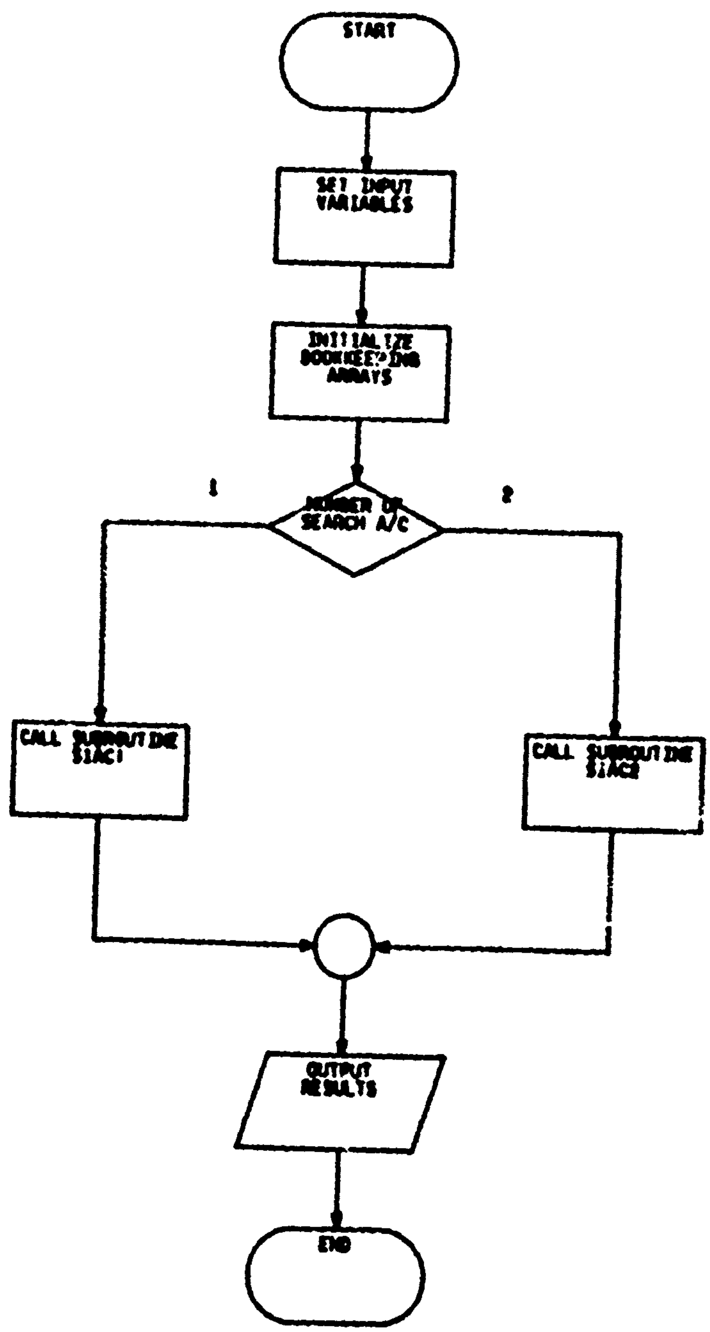
Subroutine GRIDS:

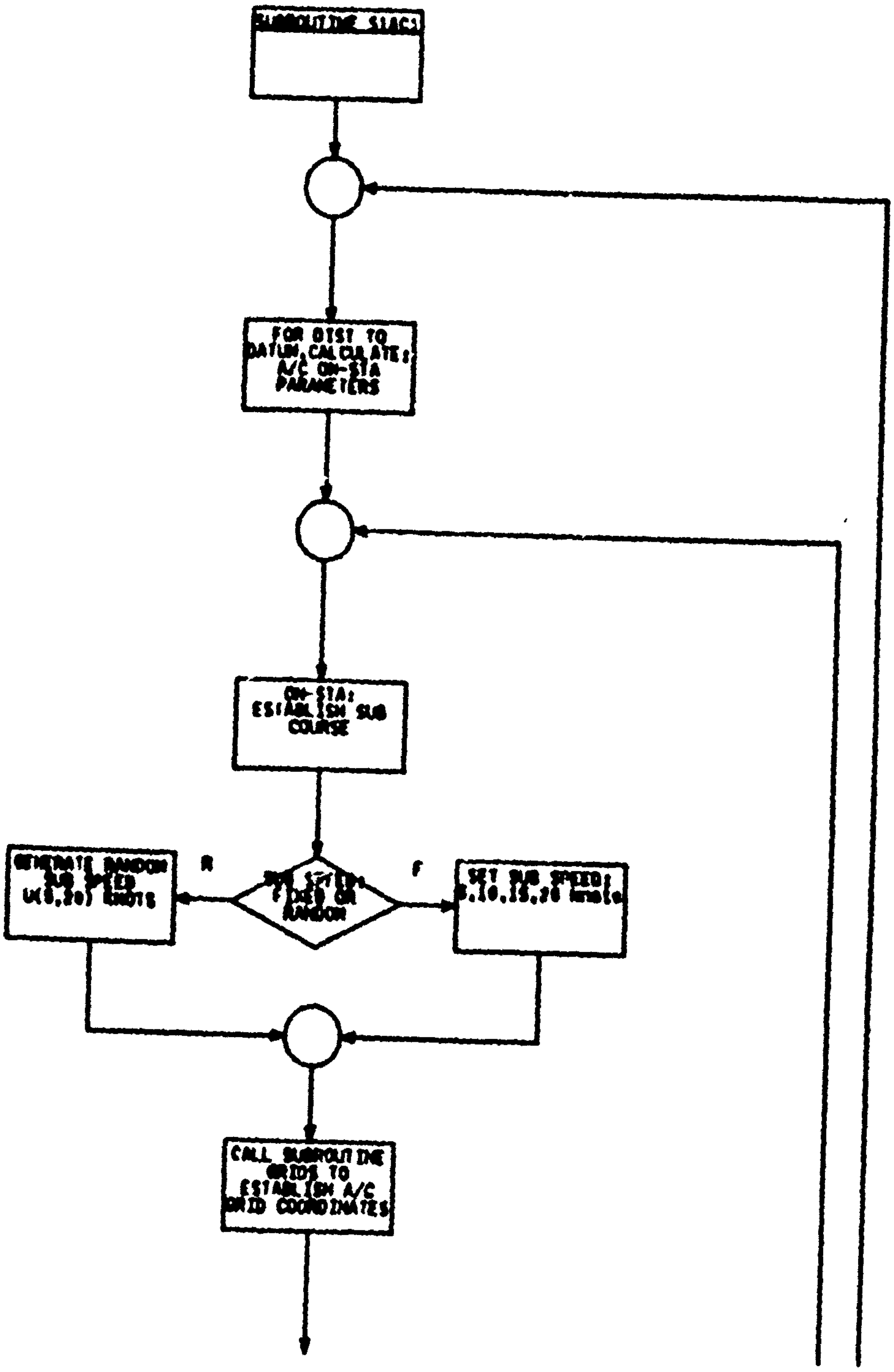
This subroutine consists of a series of imbedded loops and establishes the X and Y coordinates of the search positions for a north-oriented expanding square search pattern. It is used in the one aircraft searching scenario and for the first aircraft in the two aircraft searching scenario.

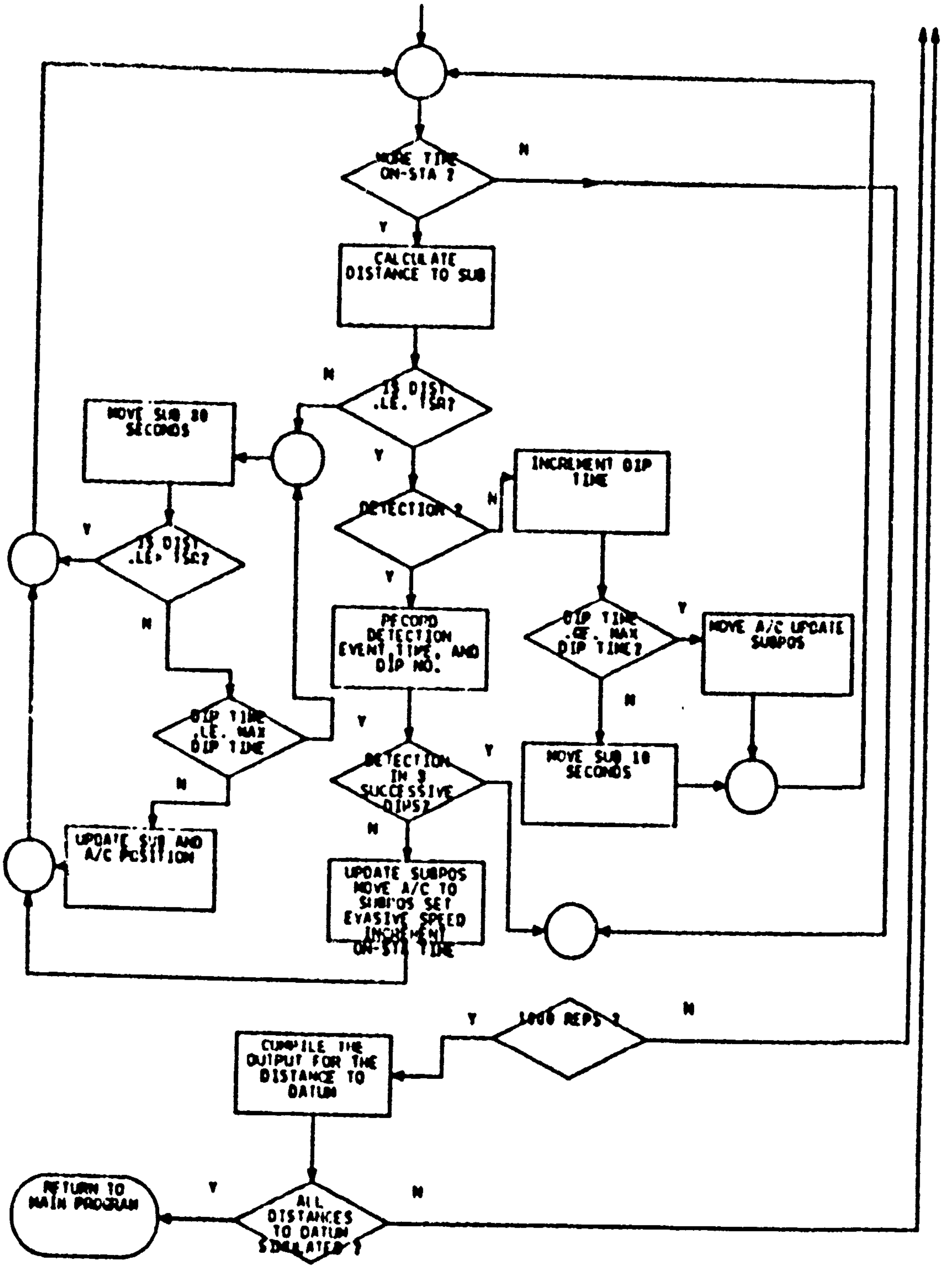
Subroutine GRIDSS:

This subroutine consists of a series of imbedded loops and establishes the X and Y coordinates of the search positions for a south-oriented expanding square search pattern. It is used for the second aircraft in the two aircraft searching scenario. The initial search position is offset one-half of the designated distance between search positions to the south and to the west.

MAIN PROGRAM




SUBROUTINE STAC3
FOR DIST TO
DATUM,CALCULATE:
A/C ON-STA
PARAMETERS
ON-STA:
ESTABLISH SUB
COURSE
R
F
GENERATE RANDOM
SUB SPEED
U(5,20) KNOTS
FIXED OR
RANDOM
SET SUB SPEED:
CALL SUBROUTINE
GRIDS TO
ESTABLISH A/C
GRID COORDINATES


MORE TIME ON-STA ?
N
Y
CALCULATE DISTANCE TO SUB
N
IS DIST .LE. TSA?
MOVE SUB 30 SECONDS
Y
INCREMENT DIP TIME
DETECTION ?
N
Y
IS DIST .LE. TSC?
Y
RECORD DETECTION EVENT TIME, AND DIP NO.
DIP TIME .GE. MAX DIP TIME?
Y
MOVE A/C UPDATE SUBPOS
N
N
DIP TIME .LE. MAX DIP TIME
Y
DETECTION IN 3 SUCCESSIVE DIPS?
Y
MOVE SUB 10 SECONDS
N
UPDATE SUB AND A/C POSITION
N
UPDATE SUBPOS MOVE A/C TO SUBPOS SET EVASIVE SPEED INCREMENT ON-STA TIME
Y
1000 REPS ?
N
COMPILE THE OUTPUT FOR THE DISTANCE TO DATUM
RETURN TO MAIN PROGRAM
Y
ALL DISTANCES TO DATUM SIMULATED ?
N

APPENDIX B

MODEL PROGRAM LISTING.

This appendix contains the program listing of the ASW pouncer mission model. An identification of the main program and the subroutines follow.

```
C       ***************************************************************
C       * THIS PROGRAM SIMULATES A CARRIER INNER ZONE ASW POUNCER SCENARIO
C       * USING ACTIVE DIPPING SONAR AT DIFFERENT DISTANCES TO DATUM
C       * AND FOR EITHER ONE OR TWO AIRCRAFT AND ONE SUBMARINE.
C       ***************************************************************
        REAL TSR,ACS,ASS,DTD,TFT,MDT,DIPDIS,SES,SIGMA,NUMDET(10)
        REAL NUMKIL(10),TER,SS,SC,SD,TEONST,DTS,DTS1,DTS2,DIPT,AX1(50)
        REAL AY1(50),AX2(50),AY2(50),SX,SY,SVX,SVY,DT,DTT,DX1,DX2,DY1
        REAL DY2,DX,DY,NUM(10,50),NUMBYT(10,50),AX1INT,AY1INT,AX2INT
        REAL AY2INT,ONSTAT,R(2),Y1,Y2,P1,P2,DPROB,DETBYT,A,B,C,DT1,DT2
        REAL PDET(10),PKILL(10),CUMNUM(10),CONPRO(10,50),CUMBYT(10)
        REAL CONPRT(10,50),Q1,Q2,TBD,FAONST,PING1(10),P1D(10)
        DOUBLE PRECISION DSEED
        INTEGER K,J,L,DTDC,REP,COUNT,FLAG,I,INDEX,M,PP,METH,X,DATUM(10),N
        INTEGER MAX,NN,TIME(50),MM,DIP(50),OO,MAXI,II,NUMAC,NUMSUB,Z,W,AC,
        &XXXX,XXX,PING,SSD
        COMMON TSR,ACS,ASS,DTD,TFT,MDT,DIPDIS,SES,SIGMA,NUMDET,NUMKIL,TER,
        &SS,SC,SD,TEONST,DTS,DTS1,DTS2,DIPT,AX1,AY1,AX2,AY2,SX,SY,SVX,SVY,D
        &T,DTT,DX1,DX2,DY1,DY2,DX,DY,NUM,NUMBYT,AX1INT,AY1INT,AX2INT,AY2INT
        &,ONSTAT,R,Y1,Y2,P1,P2,DPROB,DETBYT,A,B,C,DT1,DT2,PDET,PKILL,CUMNUM
        &,CONPRO,CUMBYT,CONPRT,Q1,Q2,DSEED,K,J,L,DTDC,REP,COUNT,FLAG,I,INDE
        &X,M,PP,METH,X,DATUM,N,MAX,NN,TIME,MM,DIP,OO,MAXI,II,NUMAC,NUMSUB,Z
        &,W,AC,TBD,FAONST,PING1,P1D,PING,SSD
C
C             INPUT VARIABLES
C
C       TSR = TACTICAL SONAR RANGE
C       NUMAC = NUMBER OF AIRCRAFT IN SCENARIO
C       NUMSUB = NUMBER OF SUBMARINES IN SCENARIO
C       MDT = MAXIMUM DIP TIME (MAX TIME TO REMAIN IN A SEARCH POSIT)
C       DSEED = INITIAL INPUT NUMBER FOR RANDOM NUMBER GENERATOR
C       DIPDIS = DISTANCE BETWEEN DIPS IN EXPANDING SQUARE SEARCH
C       SES = SUBMARINE ESCAPE SPEED
C       SIGMA = STANDARD DEVIATION WITH NORMAL DETECTION PROBABILITIES
C       METH = 1 OR 2  (1 FOR CV HELO, 2 FOR TILT ROTOR)
C       SSD = SUBMARINE SPEED OPTION (1 FOR UNIFORM(5,20), 2 FOR FIXED)
```

```
C
C         SET INPUT PARAMETERS  (ALL PROGRAM CALCULATIONS ARE IN
C         UNITS OF YARDS AND MINUTES)
C
        DO 95 XXX=3,5
        DO 96 XXXX=2,2
        METH=1
        MDT=1.0*XXXX
        SIGMA=800.0
        NUMAC=2
        NUMSUB=1
        TSR=4000.0
        DSEED=265193246
        SSD=2
        SES=30.0*2000.0/60.0

C
C           PROGRAM VARIABLES
C
C       ASS = AIRCRAFT SEARCH SPEED (EFFECTIVE SPEED BETWEEN DIPS)
C       TER = TIME ENROUTE TO DATUM
C       DTD = DISTANCE TO DATUM
C       SS = SUBMARINE SPEED
C       SC = SUBMARINE COURSE
C       SD = SUBMARINE DISTANCE TRAVELED
C       TEONST = TIME ELAPSED ON-STATION
C       ONSTAT = AVAILABLE TIME ON-STATION
C       DTS1 = DISTANCE BETWEEN SUBMARINE AND AIRCRAFT ONE
C       DTS2 = DISTANCE BETWEEN SUBMARINE AND AIRCRAFT TWO
C       AX1(I) = AIRCRAFT ONE'S X COORDINATE AT DIP POSITION I
C       AY1(I) = AIRCRAFT ONE'S Y COORDINATE AT DIP POSITION I
C       AX2(I) = AIRCRAFT TWO'S X COORDINATE AT DIP POSITION I
C       AY2(I) = AIRCRAFT TWO'S Y COORDINATE AT DIP POSITION I
C       SX = SUBMARINE X COORDINATE
C       SY = SUBMARINE Y COORDINATE
C       SVX = SUBMARINE VELOCITY IN X DIRECTION
```

```
C      SVY = SUBMARINE VELOCITY IN Y DIRECTION
C      DIPT = DIP TIME
C      DT = TIME FOR SUBMARINE TO REACH TSR GIVEN SUBMARINE WAS
C           WITHIN TSR AND WAS DETECTED
C      DX = X DISTANCE BETWEEN AIRCRAFT AND SUBMARINE
C      DY = Y DISTANCE BETWEEN AIRCRAFT AND SUBMARINE
C      DTDC = DISTANCE TO DATUM COUNTER
C      DTD = DISTANCE TO DATUM
C      P = OUTPUT PROBABILITY FROM ROUTINE MDNOR THAT A RANDOM
C          VARIABLE HAVING A NORMAL (0,1) DISTRIBUTION WILL BE LESS
C          THAN OR EQUAL TO INPUT VALUE Y
C      AC = 1 OR 2;  AIRCRAFT ONE OR AIRCRAFT TWO SPECIFIES WHICH
C          AIRCRAFT DETECTED THE SUBMARINE
C      AX1INT = INITIAL X SEARCH POSITION FOR AIRCRAFT ONE
C      AY1INT = INITIAL Y SEARCH POSITION FOR AIRCRAFT ONE
C      AX2INT = INITIAL X SEARCH POSITION FOR AIRCRAFT TWO
C      AY2INT = INITIAL Y SEARCH POSITION FOR AIRCRAFT TWO
C      N = LOOK NUMBER DURING A DIP CYCLE (1 LOOK / MIN)
C      TBD = TIME BETWEEN DIPS (TIME IT TAKES AIRCRAFT TO REPOSITION)
C      FAONST = FUEL AVAILABLE ON-STATION
C      PING = LOOK NUMBER IN A SEARCH POSITION  (OCCUR EVERY TEN SEC)
C      P1D = PROB OF DETECTION ON FIRST PING AT FIRST LOOK POSITION
C      CONPRO = CONDITIONAL PROBABILITY OF DETECTION BY DIP N
C               GIVEN A DETECTION OCCURS
C      CONPRT = CONDITIONAL PROBABILITY OF DETECTION BY A SPECIFIED
C               MISSION TIME GIVEN A DETECTION OCCURS
C
C                MAIN PROGRAM
C
C          INITIALIZE BOOKKEEPING ARRAYS
C
       MAX=0
       MAXI=0
       NN=1
       DO 2 K=1,10
       CUMNUM(K)=0.0
```

```
      NUMDET(K)=0.0
      NUMKIL(K)=0.0
      DATUM(K)=K*10.0
      CUMBYT(K)=0.0
      PING1(K)=0.0
      DO 3 L=1,50
      NUM(K,L)=0.0
      NUMBYT(K,L)=0.0
3     CONTINUE
2     CONTINUE
      IF (NUMAC.EQ.1.AND.NUMSUB.EQ.1) CALL S1AC1
      IF (NUMAC.EQ.2.AND.NUMSUB.EQ.1) CALL S1AC2
C
C          OUTPUT RESULTS
C
210   TIME(NN)=NN*10
      NN=NN+1
      IF(NN.LE.MAX) GO TO 210
      NN=1
220   DIP(NN)=NN
      NN=NN+1
      IF(NN.LE.MAXI) GO TO 220
      IF(METH.EQ.1) WRITE (8,300)
      IF(METH.EQ.2) WRITE (8,310)
      IF(SSD.EQ.1) WRITE (8,450)
      IF(SSD.EQ.2) WRITE (8,460) SS
      IF (NUMAC.EQ.1.AND.NUMSUB.EQ.1) WRITE (8,440)
      IF (NUMAC.EQ.2.AND.NUMSUB.EQ.1) WRITE (8,441)
      WRITE (8,442) XXXX,XXX
      WRITE (8,320)
      WRITE (8,330) (DATUM(X),X=1,10)
      WRITE (8,340)
      WRITE (8,350) (PDET(X),X=1,10)
      WRITE (8,355) (P1D(X),X=1,10)
      WRITE (8,360) (PKILL(X),X=1,10)
      WRITE (8,370)
```

```
      WRITE (8,320)
      WRITE (8,335) (DATUM(X),X=1,10)
      WRITE (8,340)
      MM=1
250   WRITE(8,380) TIME(MM),(CONPRT(X,MM),X=1,10)
      MM=MM+1
      IF(MM.LE.MAX) GO TO 250
      WRITE(8,340)
      WRITE(8,390)
      WRITE(8,320)
      WRITE(8,410) (DATUM(X),X=1,10)
      WRITE(8,340)
      OO=1
260   WRITE(8,400) DIP(OO),(CONPRO(X,OO),X=1,10)
      OO=OO+1
      IF(OO.LE.MAXI) GO TO 260
      WRITE(8,340)
      WRITE(8,420)
300   FORMAT ('1',27X,'CV ASW HELICOPTER',//)
310   FORMAT ('1',24X,'TILT-ROTOR (JVX-ASW VARIANT)',//)
320   FORMAT (21X,'DISTANCE TO DATUM (NAUTICAL MILES)',/)
330   FORMAT (7X,10I7)
335   FORMAT (2X,'T(MIN)',I6,9I7)
340   FORMAT (1X,78('-'),/)
350   FORMAT (1X,'P(DET)',3X,10(F6.4,1X),/)
355   FORMAT (1X,'P(PING)',2X,10(F6.4,1X),/)
360   FORMAT (1X,'P(KILL)',2X,10(F6.4,1X),//)
370   FORMAT (24X,'P(DET BY TIME T | DETECTION)',/)
380   FORMAT (2X,I3,4X,10(F6.4,1X))
390   FORMAT (25X,'P(DET BY DIP N | DETECTION)',/)
400   FORMAT (3X,I2,4X,10(F6.4,1X))
410   FORMAT (2X,'DIP #',I6,9I7)
420   FORMAT ('1')
440   FORMAT (24X,'ONE AIRCRAFT - ONE SUBMARINE',/)
441   FORMAT (24X,'TWO AIRCRAFT - ONE SUBMARINE',/)
442   FORMAT (14X,'MAX DIP TIME',1X,I1,1X,'MIN',4X,'DISTANCE BETWEEN DIP
```

```
      &S',1X,I1,1X,'NM',//)
450    FORMAT (20X,'SUBMARINE SPEED UNIFORM (5,20) KNOTS',/)
460    FORMAT (22X,'SUBMARINE SPEED FIXED',1X,F4.1,1X,'KNOTS',/)
96     CONTINUE
95     CONTINUE
       STOP
       END
C      ***********************************************
C      * SUBROUTINE FOR THE SCENARIO OF ONE AIRCRAFT *
C      * SEARCHING FOR ONE SUBMARINE                 *
C      ***********************************************
       SUBROUTINE S1AC1
       REAL TSR,ACS,ASS,DTD,TFT,MDT,DIPDIS,SES,SIGMA,NUMDET(10),NUMKIL(10
      &),TER,SS,SC,SD,TEONST,DTS,DTS1,DTS2,DIPT,AX1(50),AY1(50),AX2(50),A
      &Y2(50),SX,SY,SVX,SVY,DT,DTT,DX1,DX2,DY1,DY2,DX,DY,NUM(10,50),NUMBY
      &T(10,50),AX1INT,AY1INT,AX2INT,AY2INT,ONSTAT,R(2),Y1,Y2,P1,P2,DPROB
      &,DETBYT,A,B,C,DT1,DT2,PDET(10),PKILL(10),CUMNUM(10),CONPRO(10,50),
      &CUMBYT(10),CONPRT(10,50),Q1,Q2,TBD,FAONST,PING1(10),P1D(10)
       DOUBLE PRECISION DSEED
       INTEGER K,J,L,DTDC,REP,COUNT,FLAG,I,INDEX,M,PP,METH,X,DATUM(10),N
       INTEGER MAX,NN,TIME(50),MM,DIP(50),OO,MAXI,II,NUMAC,NUMSUB,Z,W,AC
       INTEGER PING,SSD
       COMMON TSR,ACS,ASS,DTD,TFT,MDT,DIPDIS,SES,SIGMA,NUMDET,NUMKIL,TER,
      &SS,SC,SD,TEONST,DTS,DTS1,DTS2,DIPT,AX1,AY1,AX2,AY2,SX,SY,SVX,SVY,D
      &T,DTT,DX1,DX2,DY1,DY2,DX,DY,NUM,NUMBYT,AX1INT,AY1INT,AX2INT,AY2INT
      &,ONSTAT,R,Y1,Y2,P1,P2,DPROB,DETBYT,A,B,C,DT1,DT2,PDET,PKILL,CUMNUM
      &,CONPRO,CUMBYT,CONPRT,Q1,Q2,DSEED,K,J,L,DTDC,REP,COUNT,FLAG,I,INDE
      &X,M,PP,METH,X,DATUM,N,MAX,NN,TIME,MM,DIP,OO,MAXI,II,NUMAC,NUMSUB,Z
      &,W,AC,TBD,FAONST,PING1,P1D,PING,SSD
C
C          SIMULATE SCENARIO AT 10 TO 100 NAUTICAL MILES TO DATUM
C
       DTD=0.0
       DTDC=0
5      DTD=DTD+(10.0*2000.0)
```

```
11          DTDC=DTDC+1
      C
      C      CALCULATE TIME ENROUTE TO DATUM FOR AIRCRAFT TYPE.
      C       TIME ENROUTE = LAUNCH TIME (5 MIN) + FORWARD FLIGHT
      C       TRANSITION (JVX 15 SEC ; CV HELO 20 SEC) + TIME TO
      C       TRAVEL TO DATUM AT MAX SPEED LESS DISTANCE TRAVELED
      C       DURING SPEED TRANSITIONS (JVX MAX SPEED 275 KNOTS;
      C       CV HELO MAX SPEED 180 KNOTS) + TIME FOR SPEED
      C       TRANSITION TO SLOW FLIGHT (JVX 15 SEC; CV HELO 20 SEC)
      C       + TIME TO ESTABLISH A HOVER AND LOWER DIPPING SONAR
      C
12          IF (METH.EQ.1) TER=(2.0*(20.0/60.0))+(30.0/60.0)+(DTD-(2.0*((90.0)
           &*(2000.0/60.0))*(20.0/60.0)))/(180.0*(2000.0/60.0))+5.0
14          IF (METH.EQ.2) TER=(2.0*(15.0/60.0))+(30.0/60.0)+(DTD-(2.0*((137.5
           &)*(2000.0/60.0))*(15.0/60.0)))/(275.0*(2000.0/60.0))+5.0
      C
      C       TIME BETWEEN DIPS = TIME TO RAISE SONAR (10 SEC) +
      C       TIME TO TRANSITION TO REPOSITION SPEED OF 100 KNOTS
      C       (JVX 7 SEC ; CV HELO 10 SEC) + TIME TO TRAVEL TO NEXT
      C       SEARCH POSITION LESS DISTANCE COVERED DURING TRANSITION +
      C       TIME TO TRANSITION TO HOVER SPEED (JVX 7 SEC ; CV HELO 10 SEC)
      C       TIME TO LOWER DIPPING SONAR ( 5 SEC)
      C
16          IF (METH.EQ.1) TBD=(10.0/60.0)+(10.0/60.0)+((DIPDIS-((20.0/60.0)*
           &(50.0*2000.0/60.0)))/(100.0*2000.0/60.0))+(10.0/60.0)+(5.0/60.0)
18          IF (METH.EQ.2) TBD=(10.0/60.0)+(7.0/60.0)+((DIPDIS-((14.0/60.0)*(5
           &0.0*2000.0/60.0)))/(100.0*2000.0/60.0))+(7.0/60.0)+(5.0/60.0)
      C
      C       AIRCRAFT SEARCH SPEED = DISTANCE BETWEEN DIPS
      C       DIVIDED BY TIME BETWEEN DIPS
      C
20          ASS=DIPDIS/TBD
      C
      C       ON-STATION TIME = FUEL AVAILABLE ON-STATION DIVIDED
      C       BY AVERAGE FUEL CONSUMPTION ON-STATION
      C
```

```
      IF (METH.EQ.1) FAONST=(4000.0-266.0)-(2.0*800.0*TER/60.0)
      IF (METH.EQ.2) FAONST=(12000.0-900.0)-(2.0*2900.0*TER/60.0)
      IF (METH.EQ.1) ONSTAT=FAONST/(((800.0+1100.0)/2.0)/60.0)
      IF (METH.EQ.2) ONSTAT=FAONST/(((3400.0+2700.0)/2.0)/60.0)
      DO 100 REP=1,1000
C
C       REPLICATE 1000 TIMES AT EACH DISTANCE TO DATUM
C
6     DIPT=0.0
      COUNT=0
      AX1INT=0.0
      AY1INT=0.0
      TEONST=0.0
      FLAG=0
      PING=1
      I=1
      II=1
C
C                        ON STATION
C
C
C     ESTABLISH SUB COURSE  U(0,360) DEGREES AND SPEED
C     EITHER UNIFORM (5,20) KNOTS OR FIXED
C
      IF(SSD.EQ.1) CALL GGUBS(DSEED,2,R)
      IF(SSD.EQ.2) CALL GGUBS(DSEED,1,R)
      IF(SSD.EQ.1) SS=(R(1)*15.0*(2000.0/60.0))+(5.0*(2000.0/60.0))
      IF(SSD.EQ.2) SS=10.0*2000.0/60.0
      IF(SSD.EQ.1) SC=R(2)*(2.0*3.141592654)
      IF(SSD.EQ.2) SC=R(1)*(2.0*3.141592654)
      SD=TER*SS
      SX=SD*COS(SC)
      SY=SD*SIN(SC)
C
C       ESTABLISH GRID POSITIONS FOR EXPANDING SQUARE SEARCH
C
```

```
      CALL GRIDS
C
C       STOP REPLICATION IF ON STATION TIME EXCEEDED
C
10    IF(TEONST.GE.ONSTAT) GO TO 100
C
C       CALCULATE DISTANCE TO SUB
C
      DTS1=SQRT(((SX-AX1(I))**2)+((SY-AY1(I))**2))
      IF(DTS1.GT.TSR) PING=PING+1
      IF(DTS1.GT.TSR) GO TO 60
C
C     SUB IS WITHIN TSR AT BEGINNING OF DIP OR HAS MOVED TO WITHIN TSR
C       CALCULATE PROBABILITY OF DETECTION USING NORMAL DIST OF TSR
C
      Y1=(DTS1-(TSR/2.0))/SIGMA
      CALL MDNOR(Y1,P1)
      CALL GGUBS(DSEED,1,R)
C
C       DETERMINE IF DETECTION IS MADE. IF NO DETECTION MADE
C       DETERMINE IF TIME REMAINS TO SEARCH IN CURRENT POSITION
C
      IF(R(1).GE.P1) GO TO 40
      PING=PING+1
      DIPT=DIPT+(10.0/60.0)
      IF (DIPT.GT.MDT) GO TO 20
C
C        UPDATE SUB POSITION. AIRCRAFT REMAINS IN CURRENT POSITION
C
      SD=SS*(10.0/60.0)
      CALL SUBPOS
      GO TO 10
C
C       IF NO DETECTION IS MADE IN CURRENT POSITION WITHIN MAX SEARCH
C       TIME MOVE AIRCRAFT TO NEXT GRID POSITION AND UPDATE SUBS POSIT
C
```

```
20    IF(FLAG.GT.0) FLAG=0
      I=I+1
      II=I
      TEONST=TEONST+DIPT
      SD=SS*MDT
      CALL SUBPOS
30    IF(FLAG.GT.0) SD=SS*(TSR/ASS)
      IF(FLAG.EQ.0) SD=SS*(DIPDIS/ASS)
      CALL SUBPOS
      DIPT=0.0
      IF(FLAG.GT.0) TEONST=TEONST+(TSR/ASS)
      IF(FLAG.EQ.0) TEONST=TEONST+(DIPDIS/ASS)
      GO TO 10
C
C        DETECTION OCCURS
C
40    FLAG=FLAG+1
      TEONST=TEONST+DIPT
C
C        DETERMINE IF DETECTION IS SUCCESSIVE
C
      IF(COUNT.GT.0) GO TO 50
C
C         BOOKKEEPING
C
      NUMDET(DTDC)=NUMDET(DTDC)+1
      NUM(DTDC,II)=NUM(DTDC,II)+1
      IF(II.EQ.1.AND.PING.EQ.1) PING1(DTDC)=PING1(DTDC)+1
      IF(II.GT.MAXI) MAXI=II
      DETBYT=(TEONST+TER)/10.0
      INDEX=IFIX(DETBYT)+1
      NUMBYT(DTDC,INDEX)=NUMBYT(DTDC,INDEX)+1
      IF(INDEX.GT.MAX) MAX=INDEX
50    COUNT=1
      IF(FLAG.EQ.3) NUMKIL(DTDC)=NUMKIL(DTDC)+1
C
```

```
      C        STOP REPLICATION IF DETECTION OCCURS
      C        IN 3 SUCCESSIVE DIP POSITIONS
      C
105         IF(FLAG.EQ.3) GO TO 100
      C
      C     DETERMINE TIME THAT THE SUBMARINE WILL BE AT TSR GIVEN IT WAS
      C     WITHIN TSR AND DETECTED.  UPDATE SUBMARINE POSITION ACCORDINGLY
      C
106         DX=SX-AX1(I)
107         DY=SY-AY1(I)
108         SVX=SS*COS(SC)
109         SVY=SS*SIN(SC)
110         A=(SVX**2)+(SVY**2)
111         B=2.0*((DX*SVX)+(DY*SVY))
112         C=(DX**2)+(DY**2)-(TSR**2)
113         DT1=(-B+SQRT((B**2)-(4.0*(A*C))))/(2.0*A)
114         DT2=(-B-SQRT((B**2)-(4.0*(A*C))))/(2.0*A)
115         DT=DT1
116         IF(DT2.GT.DT1) DT=DT2
118         TEONST=TEONST+DT
119         SD=SS*DT
120         CALL SUBPOS
      C
      C       SUBMARINE TAKES EVASIVE ACTION UPON BEING DETECTED.
      C       COURSE: U(0,360) DEGREES   SPEED: ESCAPE SPEED
      C
121         CALL GGUBS(DSEED,1,R)
122         SC=R(1)*(2.0*3.141592654)
123         SS=SES
      C
      C       MOVE AIRCRAFT TO SUBMARINE'S POSITION WHEN IT REACHED TSR.
      C       ESTABLISH NEW GRID POSITIONS FOR EXPANDING SQUARE SEARCH
      C       TO BE USED IF THE AIRCRAFT DOES NOT DETECT ON NEXT LOOK
      C
124         AX1INT=SX
125         AY1INT=SY
```

```
      CALL GRIDS
      I=1
      II=II+1
      GO TO 30
C
C        IF SUBMARINE IS NOT WITHIN TSR, MOVE SUB ONE MINUTE AND
C        DETERMINE IF WITHIN TSR. IF SUB MOVES WITHIN TSR CHECK FOR
C        DETECTION.  IF SUB DOES NOT MOVE TO WITHIN TSR WITHIN
C        MAX DIP SEARCH TIME MOVE AIRCRAFT TO NEXT SEARCH POSITION
C
 60   IF(FLAG.GT.0) FLAG=0
      N=1
 61   SD=SS*(MDT/5.0)
      CALL SUBPOS
      DTS1=SQRT(((SX-AX1(I))**2)+((SY-AY1(I))**2))
      DIPT=DIPT+(MDT/5.0)
      TEONST=TEONST+(MDT/5.0)
      N=N+1
      IF(N.LE.5.AND.DTS1.GT.TSR) GO TO 61
      IF(DTS1.LE.TSR) GO TO 10
      I=I+1
      II=I
      GO TO 30
C
C        END REPLICATION LOOP
C
 100  CONTINUE
C
C        COMPILE THE OUTPUT
C
      PDET(DTDC)=NUMDET(DTDC)/(1000.0)
      PKILL(DTDC)=NUMKIL(DTDC)/(1000.0)
      P1D(DTDC)=PING1(DTDC)/(1000.0)
      IF(NUMDET(DTDC).EQ.0.0) GO TO 200
      M=1
 90   CUMNUM(DTDC)=CUMNUM(DTDC)+NUM(DTDC,M)
```

```
      CONPRO(DTDC,M)=CUMNUM(DTDC)/NUMDET(DTDC)
      CUMBYT(DTDC)=CUMBYT(DTDC)+NUMBYT(DTDC,M)
      CONPRT(DTDC,M)=CUMBYT(DTDC)/NUMDET(DTDC)
      M=M+1
      IF(M.LE.50) GO TO 90
C
C         END DISTANCE TO DATUM LOOP
C
200   IF(DTDC.LT.10) GO TO 5
      SS=10.0
      RETURN
      END

C     *******************************************
C      SUBROUTINE FOR THE SCENARIO OF TWO AIRCRAFT
C      SEARCHING FOR ONE SUBMARINE
C     *******************************************
      SUBROUTINE S1AC2
      REAL TSR,ACS,ASS,DTD,TFT,MDT,DIPDIS,SES,SIGMA,NUMDET(10),NUMKIL(10
     &),TER,SS,SC,SD,TEONST,DTS,DTS1,DTS2,DIPT,AX1(50),AY1(50),AX2(50),A
     &Y2(50),SX,SY,SVX,SVY,DT,DTT,DX1,DX2,DY1,DY2,DX,DY,NUM(10,50),NUMBY
     &T(10,50),AX1INT,AY1INT,AX2INT,AY2INT,ONSTAT,R(2),Y1,Y2,P1,P2,DPROB
     &,DETBYT,A,B,C,DT1,DT2,PDET(10),PKILL(10),CUMNUM(10),CONPRO(10,50),
     &CUMBYT(10),CONPRT(10,50),Q1,Q2,TBD,FAONST,PING1(10),P1D(10)
      DOUBLE PRECISION DSEED
      INTEGER K,J,L,DTDC,REP,COUNT,FLAG,I,INDEX,M,PP,METH,X,DATUM(10),N
      INTEGER MAX,NN,TIME(50),MM,DIP(50),OO,MAXI,II,NUMAC,NUMSUB,Z,W,AC
      INTEGER PING,SSD
      COMMON TSR,ACS,ASS,DTD,TFT,MDT,DIPDIS,SES,SIGMA,NUMDET,NUMKIL,TER,
     &SS,SC,SD,TEONST,DTS,DTS1,DTS2,DIPT,AX1,AY1,AX2,AY2,SX,SY,SVX,SVY,D
     &T,DTT,DX1,DX2,DY1,DY2,DX,DY,NUM,NUMBYT,AX1INT,AY1INT,AX2INT,AY2INT
     &,ONSTAT,R,Y1,Y2,P1,P2,DPROB,DETBYT,A,B,C,DT1,DT2,PDET,PKILL,CUMNUM
     &,CONPRO,CUMBYT,CONPRT,Q1,Q2,DSEED,K,J,L,DTDC,REP,COUNT,FLAG,I,INDE
     &X,M,PP,METH,X,DATUM,N,MAX,NN,TIME,MM,DIP,OO,MAXI,II,NUMAC,NUMSUB,Z
     &,W,AC,TBD,FAONST,PING1,P1D,PING,SSD
C
```

```
C         SIMULATE SCENARIO AT 10 TO 100 NAUTICAL MILES TO DATUM
C
      DTD=0.0
      DTDC=0
    5 DTD=DTD+(10.0*2000.0)
      DTDC=DTDC+1
C
C       CALCULATE TIME ENROUTE TO DATUM FOR AIRCRAFT TYPE.
C        TIME ENROUTE = LAUNCH TIME (5 MIN) + FORWARD FLIGHT
C        TRANSITION (JVX 15 SEC ; CV HELO 20 SEC) + TIME TO
C        TRAVEL TO DATUM AT MAX SPEED LESS DISTANCE TRAVELED
C        DURING SPEED TRANSITIONS (JVX MAX SPEED 275 KNOTS;
C        CV HELO MAX SPEED 180 KNOTS) + TIME FOR SPEED
C        TRANSITION TO SLOW FLIGHT (JVX 15 SEC; CV HELO 20 SEC)
C        + TIME TO ESTABLISH A HOVER AND LOWER DIPPING SONAR
C
      IF (METH.EQ.1) TER=(2.0*(20.0/60.0))+(30.0/60.0)+(DTD-(2.0*((90.0)
     &*(2000.0/60.0))*(20.0/60.0)))/(180.0*(2000.0/60.0))+5.0
      IF (METH.EQ.2) TER=(2.0*(15.0/60.0))+(30.0/60.0)+(DTD-(2.0*((137.5
     &)*(2000.0/60.0))*(15.0/60.0)))/(275.0*(2000.0/60.0))+5.0
C
C        TIME BETWEEN DIPS = TIME TO RAISE SONAR (10 SEC) +
C        TIME TO TRANSITION TO REPOSITION SPEED OF 100 KNOTS
C        (JVX 7 SEC ; CV HELO 10 SEC) + TIME TO TRAVEL TO NEXT
C        SEARCH POSITION LESS DISTANCE COVERED DURING TRANSITION +
C        TIME TO TRANSITION TO HOVER SPEED (JVX 7 SEC ; CV HELO 10 SEC)
C        TIME TO LOWER DIPPING SONAR ( 5 SEC)
C
      IF (METH.EQ.1) TBD=(10.0/60.0)+(10.0/60.0)+((DIPDIS-((20.0/60.0)*
     &(50.0*2000.0/60.0)))/(100.0*2000.0/60.0))+(10.0/60.0)+(5.0/60.0)
      IF (METH.EQ.2) TBD=(10.0/60.0)+(7.0/60.0)+((DIPDIS-((14.0/60.0)*(5
     &0.0*2000.0/60.0)))/(100.0*2000.0/60.0))+(7.0/60.0)+(5.0/60.0)
C
C        AIRCRAFT SEARCH SPEED = DISTANCE BETWEEN DIPS
C        DIVIDED BY TIME BETWEEN DIPS
C
```

```
      ASS=DIPDIS/TBD
C
C       ON-STATION TIME = FUEL AVAILABLE ON-STATION DIVIDED
C       BY AVERAGE FUEL CONSUMPTION ON-STATION
C
      IF (METH.EQ.1) FAONST=(2000.0-266.0)-(2.0*800.0*TER/60.0)
      IF (METH.EQ.2) FACNST=(12000.0-900.0)-(2.0*2900.0*TER/60.0)
      IF (METH.EQ.1) ONSTAT=FAONST/(((800.0+1100.0)/2.0)/60.0)
      IF (METH.EQ.2) ONSTAT=FAONST/(((3400.0+2700.0)/2.0)/60.0)
      DO 100 REP=1,1000
C
C       REPLICATE 1000 TIMES AT EACH DISTANCE TO DATUM
C
6     DIPT=0.0
      COUNT=0
      TEONST=0.0
      FLAG=0
      PING=1
      I=1
      II=1
C
C                    ON STATION
C
C
C     ESTABLISH SUB COURSE  U(0,360) DEGREES AND SUB SPEED
C     EITHER UNIFORM (5,20) OR FIXED KNOTS
      IF(SSD.EQ.1) CALL GGUBS(DSEED,2,R)
      IF(SSD.EQ.2) CALL GGUBS(DSEED,1,R)
      IF(SSD.EQ.1) SS=(R(1)*15.0*(2000.0/60.0))+(5.0*2000.0/60.0)
      IF(SSD.EQ.2) SS=20.0*2000.0/60.0
      IF(SSD.EQ.1) SC=R(2)*(2.0*3.141592654)
      IF(SSD.EQ.2) SC=R(1)*(2.0*3.141592654)
      SD=TER*SS
      SX=SD*COS(SC)
      SY=SD*SIN(SC)
C
```

```
C       ESTABLISH GRID POSITIONS FOR EXPANDING SQUARE SEARCHES
C
      AX1INT=0.0
      AY1INT=0.0
      AX2INT=-0.5*DIPDIS
      AY2INT=-0.5*DIPDIS
      CALL GRIDS
      CALL GRIDSS
C
C       STOP REPLICATION IF ON STATION TIME EXCEEDED
C
 10   IF(TEONST.GE.ONSTAT) GO TO 100
C
C       CALCULATE DISTANCE TO SUB FOR EACH AIRCRAFT
C
      DTS1=SQRT(((SX-AX1(I))**2)+((SY-AY1(I))**2))
      DTS2=SQRT(((SX-AX2(I))**2)+((SY-AY2(I))**2))
C
C       DETERMINE IF EITHER, NONE, OR BOTH AIRCRAFT
C       ARE WITHIN TACTICAL SONAR RANGE OF THE SUBMARINE
C
      IF(DTS1.GT.TSR.AND.DTS2.GT.TSR) PING=PING+1
      IF(DTS1.GT.TSR.AND.DTS2.GT.TSR) GO TO 60
      IF(DTS1.GT.TSR.AND.DTS2.LE.TSR) GO TO 80
      IF(DTS1.LE.TSR.AND.DTS2.LE.TSR) GO TO 85
      Y1=(DTS1-(TSR/2.0))/SIGMA
      CALL MDNOR(Y1,P1)
      CALL GGUBS(DSEED,1,R)
C
C        DETERMINE IF AIRCRAFT ONE DETECTS THE SUBMARINE
C
      IF(R(1).GE.P1) AC=1
      IF(R(1).GE.P1) GO TO 40
      PING=PING+1
      DIPT=DIPT+(10.0/60.0)
      IF(DIPT.GT.MDT) GO TO 20
```

```
           SD=SS*(10.0/60.0)
           CALL SUBPOS
           GO TO 10
   80      Y2=(DTS2-(TSR/2.0))/SIGMA
           CALL MDNOR(Y2,P2)
           CALL GGUBS(DSEED,1,R)
C
C              DETERMINE IF AIRCRAFT TWO DETECTS THE SUBMARINE
C
           IF(R(1).GE.P2) AC=2
           IF(R(1).GE.P2) GO TO 40
           PING=PING+1
           DIPT=DIPT+(10.0/60.0)
           IF(DIPT.GT.MDT) GO TO 20
           SD=SS*(10.0/60.0)
           CALL SUBPOS
           GO TO 10
C
C             DETERMINE IF EITHER OR BOTH AIRCRAFT DETECTS THE SUBMARINE
C
   85      Y1=(DTS1-(TSR/2.0))/SIGMA
           Y2=(DTS2-(TSR/2.0))/SIGMA
           CALL MDNOR(Y1,P1)
           CALL GGUBS(DSEED,1,R)
           Q1=R(1)
           CALL MDNOR(Y2,P2)
           CALL GGUBS(DSEED,1,R)
           Q2=R(1)
           IF(Q1.GE.P1) AC=1
           IF(Q2.GE.P2) AC=2
           IF(Q1.GE.P1.OR.Q2.GE.P2) GO TO 40
           PING=PING+1
           DIPT=DIPT+(10.0/60.0)
           IF(DIPT.GT.MDT) GO TO 20
           SD=SS*(10.0/60.0)
           CALL SUBPOS
```

```
108              GO TO 10
          C
          C        IF NO DETECTION IS MADE IN CURRENT POSITION WITHIN MAX SEARCH
          C        TIME MOVE AIRCRAFT TO NEXT GRID POSITION AND UPDATE SUBS POSIT
          C
109       20     IF(FLAG.GT.0) FLAG=0
111              I=I+1
112              II=I
113              TEONST=TEONST+DIPT
114              SD=SS*MDT
115              CALL SUBPOS
116       30     IF(FLAG.GT.0) SD=SS*(TSR/ASS)
118              IF(FLAG.EQ.0) SD=SS*(DIPDIS/ASS)
120              CALL SUBPOS
121              DIPT=0.0
122              IF(FLAG.GT.0) TEONST=TEONST+(TSR/ASS)
124              IF(FLAG.EQ.0) TEONST=TEONST+(DIPDIS/ASS)
126              GO TO 10
          C
          C         DETECTION OCCURS
          C
127       40     FLAG=FLAG+1
128              TEONST=TEONST+DIPT
          C
          C         DETERMINE IF DETECTION IS SUCCESSIVE
          C
129              IF(COUNT.GT.0) GO TO 50
          C
          C          BOOKKEEPING
          C
130              NUMDET(DTDC)=NUMDET(DTDC)+1
131              NUM(DTDC,II)=NUM(DTDC,II)+1
132              IF(II.EQ.1.AND.PING.EQ.1) PING1(DTDC)=PING1(DTDC)+1
134              IF(II.GT.MAXI) MAXI=II
136              DETBYT=(TEONST+TER)/10.0
137              INDEX=IFIX(DETBYT)+1
```

```
      NUMBYT(DTDC,INDEX)=NUMBYT(DTDC,INDEX)+1
      IF(INDEX.GT.MAX) MAX=INDEX
50    COUNT=1
      IF(FLAG.EQ.3) NUMKIL(DTDC)=NUMKIL(DTDC)+1
C
C        STOP REPLICATION IF DETECTION OCCURS
C        IN 3 SUCCESSIVE DIP POSITIONS
C
      IF(FLAG.EQ.3) GO TO 100
C
C     DETERMINE TIME THAT THE SUBMARINE WILL BE AT TSR GIVEN IT WAS
C     WITHIN TSR AND DETECTED.  UPDATE SUBMARINE POSITION ACCORDINGLY
C     AND WITH RESPECT TO WHICH AIRCRAFT IT WAS DETECTED BY
C
      IF(AC.EQ.1) DX=SX-AX1(I)
      IF(AC.EQ.1) DY=SY-AY1(I)
      IF(AC.EQ.2) DX=SX-AX2(I)
      IF(AC.EQ.2) DY=SY-AY2(I)
      SVX=SS*COS(SC)
      SVY=SS*SIN(SC)
      A=(SVX**2)+(SVY**2)
      B=2.0*((DX*SVX)+(DY*SVY))
      C=(DX**2)+(DY**2)-(TSR**2)
      DT1=(-B+SQRT((B**2)-(4.0*(A*C))))/(2.0*A)
      DT2=(-B-SQRT((B**2)-(4.0*(A*C))))/(2.0*A)
      DT=DT1
      IF(DT2.GT.DT1) DT=DT2
      TEONST=TEONST+DT
      SD=SS*DT
      CALL SUBPOS
C
C       SUBMARINE TAKES EVASIVE ACTION UPON BEING DETECTED.
C       COURSE: U(0,360) DEGREES   SPEED: ESCAPE SPEED
C
      CALL GGUBS(DSEED,1,R)
      SC=R(1)*(2.0*3.141592654)
```

```
      SS=SES
C
C       MOVE AIRCRAFT TO SUBMARINE'S POSITION WHEN IT REACHED TSR.
C       ESTABLISH NEW GRID POSITIONS FOR EXPANDING SQUARE SEARCH
C       TO BE USED IF THE AIRCRAFT DOES NOT DETECT ON NEXT LOOK
C
      AX1INT=SX
      AY1INT=SY
      CALL GRIDS
      I=1
      II=II+1
      GO TO 30
C
C        IF SUBMARINE IS NOT WITHIN TSR, MOVE SUB ONE MINUTE AND
C        DETERMINE IF WITHIN TSR. IF SUB MOVES WITHIN TSR CHECK FOR
C        DETECTION.  IF SUB DOES NOT MOVE TO WITHIN TSR WITHIN
C        MAX DIP SEARCH TIME MOVE AIRCRAFT TO NEXT SEARCH POSITION
C
60    IF(FLAG.GT.0) FLAG=0
      N=1
61    SD=SS*(MDT/5.0)
      CALL SUBPOS
      DTS1=SQRT(((SX-AX1(I))**2)+((SY-AY1(I))**2))
      DTS2=SQRT(((SX-AX2(I))**2)+((SY-AY2(I))**2))
      DTS=DTS1
      IF(DTS2.LE.DTS) DTS=DTS2
      DIPT=DIPT+(MDT/5.0)
      TEONST=TEONST+(MDT/5.0)
      N=N+1
      IF(N.LE.5.AND.DTS.GT.TSR) GO TO 61
      IF(DTS.LE.TSR) GO TO 10
      I=I+1
      II=I
      GO TO 30
C
C        END REPLICATION LOOP
```

```
C
100   CONTINUE
C
C        COMPILE THE OUTPUT
C
      PDET(DTDC)=NUMDET(DTDC)/(1000.0)
      PKILL(DTDC)=NUMKIL(DTDC)/(1000.0)
      P1D(DTDC)=PING1(DTDC)/(1000.0)
      IF(NUMDET(DTDC).EQ.0.0) GO TO 200
      M=1
90    CUMNUM(DTDC)=CUMNUM(DTDC)+NUM(DTDC,M)
      CONPRO(DTDC,M)=CUMNUM(DTDC)/NUMDET(DTDC)
      CUMBYT(DTDC)=CUMBYT(DTDC)+NUMBYT(DTDC,M)
      CONPRT(DTDC,M)=CUMBYT(DTDC)/NUMDET(DTDC)
      M=M+1
      IF(M.LE.50) GO TO 90
C
C         END DISTANCE TO DATUM LOOP                    *
C
200   IF(DTDC.LT.10) GO TO 5
      SS=20.0
      RETURN
      END
C     ***********************************************************
C     SUBROUTINE TO CALCULATE SUBMARINE X AND Y COORDINATES BASED
C     ON DISTANCE TRAVELED AND COURSE IN RADIANS.
C     *************************************************************
      SUBROUTINE SUBPOS
      REAL TSR,ACS,ASS,DTD,TFT,MDT,DIPDIS,SES,SIGMA,NUMDET(10),NUMKIL(10
     &),TER,SS,SC,SD,TEONST,DTS,DTS1,DTS2,DIPT,AX1(50),AY1(50),AX2(50),A
     &Y2(50),SX,SY,SVX,SVY,DT,DTT,DX1,DX2,DY1,DY2,DX,DY,NUM(10,50),NUMBY
     &T(10,50),AX1INT,AY1INT,AX2INT,AY2INT,ONSTAT,R(2),Y1,Y2,P1,P2,DPROB
     &,DETBYT,A,B,C,DT1,DT2,PDET(10),PKILL(10),CUMNUM(10),CONPRO(10,50),
     &CUMBYT(10),CONPRT(10,50),Q1,Q2
      DOUBLE PRECISION DSEED
```

```
 4          INTEGER K,J,L,DTDC,REP,COUNT,FLAG,I,INDEX,M,PP,METH,X,DATUM(10),N
 5          INTEGER MAX,NN,TIME(50),MM,DIP(50),OO,MAXI,II,NUMAC,NUMSUB,Z,W,AC
 6          COMMON TSR,ACS,ASS,DTD,TFT,MDT,DIPDIS,SES,SIGMA,NUMDET,NUMKIL,TER,
           &SS,SC,SD,TEONST,DTS,DTS1,DTS2,DIPT,AX1,AY1,AX2,AY2,SX,SY,SVX,SVY,D
           &T,DTT,DX1,DX2,DY1,DY2,DX,DY,NUM,NUMBYT,AX1INT,AY1INT,AX2INT,AY2INT
           &,ONSTAT,R,Y1,Y2,P1,P2,DPROB,DETBYT,A,B,C,DT1,DT2,PDET,PKILL,CUMNUM
           &,CONPRO,CUMBYT,CONPRT,Q1,Q2,DSEED,K,J,L,DTDC,REP,COUNT,FLAG,I,INDE
           &X,M,PP,METH,X,DATUM,N,MAX,NN,TIME,MM,DIP,OO,MAXI,II,NUMAC,NUMSUB,Z
           &,W,AC
 7          SX=SX+(SD*COS(SC))
 8          SY=SY+(SD*SIN(SC))
 9          RETURN
10          END
      C     ******************************************************************
      C     SUBROUTINE TO CALCULATE GRID POSITIONS FOR AIRCRAFT ONE FOR A
      C     CLOCKWISE EXPANDING SQUARE SEARCH WITH INITIAL NORTH MOVEMENT.
      C     ******************************************************************
 1          SUBROUTINE GRIDS
 2          REAL TSR,ACS,ASS,DTD,TFT,MDT,DIPDIS,SES,SIGMA,NUMDET(10),NUMKIL(10
           &),TER,SS,SC,SD,TEONST,DTS,DTS1,DTS2,DIPT,AX1(50),AY1(50),AX2(50),A
           &Y2(50),SX,SY,SVX,SVY,DT,DTT,DX1,DX2,DY1,DY2,DX,DY,NUM(10,50),NUMBY
           &T(10,50),AX1INT,AY1INT,AX2INT,AY2INT,ONSTAT,R(2),Y1,Y2,P1,P2,DPROB
           &,DETBYT,A,B,C,DT1,DT2,PDET(10),PKILL(10),CUMNUM(10),CONPRO(10,50),
           &CUMBYT(10),CONPRT(10,50),Q1,Q2
 3          DOUBLE PRECISION DSEED
 4          INTEGER K,J,L,DTDC,REP,COUNT,FLAG,I,INDEX,M,PP,METH,X,DATUM(10),N
 5          INTEGER MAX,NN,TIME(50),MM,DIP(50),OO,MAXI,II,NUMAC,NUMSUB,Z,W,AC
 6          COMMON TSR,ACS,ASS,DTD,TFT,MDT,DIPDIS,SES,SIGMA,NUMDET,NUMKIL,TER,
           &SS,SC,SD,TEONST,DTS,DTS1,DTS2,DIPT,AX1,AY1,AX2,AY2,SX,SY,SVX,SVY,D
           &T,DTT,DX1,DX2,DY1,DY2,DX,DY,NUM,NUMBYT,AX1INT,AY1INT,AX2INT,AY2INT
           &,ONSTAT,R,Y1,Y2,P1,P2,DPROB,DETBYT,A,B,C,DT1,DT2,PDET,PKILL,CUMNUM
           &,CONPRO,CUMBYT,CONPRT,Q1,Q2,DSEED,K,J,L,DTDC,REP,COUNT,FLAG,I,INDE
           &X,M,PP,METH,X,DATUM,N,MAX,NN,TIME,MM,DIP,OO,MAXI,II,NUMAC,NUMSUB,Z
           &,W,AC
 7          AX1(1)=AX1INT
```

```
      AY1(1)=AY1INT
      W=1
      Z=1
690   DO 700 J=1,Z
      AX1(J+W)=AX1(J+W-1)
      AY1(J+W)=AY1(J+W-1)+DIPDIS
700   CONTINUE
      W=W+Z
      DO 710 J=1,Z
      AX1(J+W)=AX1(J+W-1)+DIPDIS
      AY1(J+W)=AY1(J+W-1)
710   CONTINUE
      W=W+Z
      Z=Z+1
      DO 720 J=1,Z
      AX1(J+W)=AX1(J+W-1)
      AY1(J+W)=AY1(J+W-1)-DIPDIS
720   CONTINUE
      W=W+Z
      DO 730 J=1,Z
      AX1(J+W)=AX1(J+W-1)-DIPDIS
      AY1(J+W)=AY1(J+W-1)
730   CONTINUE
      W=W+Z
      Z=Z+1
      IF(W.LE.30) GO TO 690
      RETURN
      END
C     ***************************************************************
C     SUBROUTINE TO CALCULATE GRID POSITIONS FOR AIRCRAFT TWO FOR A
C     CLOCKWISE EXPANDING SQUARE SEARCH WITH INITIAL SOUTH MOVEMENT.
C     ***************************************************************
      SUBROUTINE GRIDSS
      REAL TSR,ACS,ASS,DTD,TFT,MDT,DIPDIS,SES,SIGMA,NUMDET(10),NUMKIL(10
     &),TER,SS,SC,SD,TEONST,DTS,DTS1,DTS2,DIPT,AX1(50),AY1(50),AX2(50),A
```

```
&Y2(50),SX,SY,SVX,SVY,DT,DTT,DX1,DX2,DY1,DY2,DX,DY,NUM(10,50),NUMBY
&T(10,50),AX1INT,AY1INT,AX2INT,AY2INT,ONSTAT,R(2),Y1,Y2,P1,P2,DPROB
&,DETBYT,A,B,C,DT1,DT2,PDET(10),PKILL(10),CUMNUM(10),CONPRO(10,50),
&CUMBYT(10),CONPRT(10,50),Q1,Q2
      DOUBLE PRECISION DSEED
      INTEGER K,J,L,DTDC,REP,COUNT,FLAG,I,INDEX,M,PP,METH,X,DATUM(10),N
      INTEGER MAX,NN,TIME(50),MM,DIP(50),OO,MAXI,II,NUMAC,NUMSUB,Z,W,AC
      COMMON TSR,ACS,ASS,DTD,TFT,MDT,DIPDIS,SES,SIGMA,NUMDET,NUMKIL,TER,
&SS,SC,SD,TEONST,DTS,DTS1,DTS2,DIPT,AX1,AY1,AX2,AY2,SX,SY,SVX,SVY,D
&T,DTT,DX1,DX2,DY1,DY2,DX,DY,NUM,NUMBYT,AX1INT,AY1INT,AX2INT,AY2INT
&,ONSTAT,R,Y1,Y2,P1,P2,DPROB,DETBYT,A,B,C,DT1,DT2,PDET,PKILL,CUMNUM
&,CONPRO,CUMBYT,CONPRT,Q1,Q2,DSEED,K,J,L,DTDC,REP,COUNT,FLAG,I,INDE
&X,M,PP,METH,X,DATUM,N,MAX,NN,TIME,MM,DIP,OO,MAXI,II,NUMAC,NUMSUB,Z
&,W,AC
      AX2(1)=AX2INT
      AY2(1)=AY2INT
      W=1
      Z=1
690   DO 700 J=1,Z
      AX2(J+W)=AX2(J+W-1)
      AY2(J+W)=AY2(J+W-1)-DIPDIS
700   CONTINUE
      W=W+Z
      DO 710 J=1,Z
      AX2(J+W)=AX2(J+W-1)-DIPDIS
      AY2(J+W)=AY2(J+W-1)
710   CONTINUE
      W=W+Z
      Z=Z+1
      DO 720 J=1,Z
      AX2(J+W)=AX2(J+W-1)
      AY2(J+W)=AY2(J+W-1)+DIPDIS
720   CONTINUE
      W=W+Z
      DO 730 J=1,Z
      AX2(J+W)=AX2(J+W-1)+DIPDIS
```

```
      AY2(J+W)=AY2(J+W-1)
730   CONTINUE
      W=W+Z
      Z=Z+1
      IF(W.LE.30) GO TO 690
      RETURN
      END
```

APPENDIX C

REPRESENTATIVE EXAMPLES OF PROGRAM OUTPUT.

The model was run for all combinations of one and two aircraft searching, distances between search positions of three, four, and five nautical miles, and submarine speeds either fixed at five, ten, fifteen and twenty knots. Additionally, the case where the submarine's speed is distributed Uniformly between five and twenty knots was run. A total of sixty runs were performed. This appendix contains a representative cross section of the model output. A listing of those included follows.

Aircraft Type	No. searching	Distance between dips	Subspeed	Page
CV Helo	1	5	U(5,20)	121
JVX	1	3	U(5,20)	122
CV Helo	2	5	5.0	123
JVX	2	5	5.0	124
CV Helo	1	3	10.0	125
JVX	1	5	10.0	126
CV Helo	2	4	15.0	127
JVX	2	4	15.0	128
CV Helo	2	5	20.0	129
JVX	1	5	20.0	130

CV ASW HELICOPTER

SUBMARINE SPEED UNIFORM (5,20) KNOTS

ONE AIRCRAFT - ONE SUBMARINE

MAX DIP TIME 2 MIN   DISTANCE BETWEEN DIPS 5 NM

DISTANCE TO DATUM (NAUTICAL MILES)

	10	20	30	40	50	60	70	80	90	100
P(DET)	0.4930	0.3540	0.3020	0.2340	0.2100	0.1350	0.1370	0.1500	0.1150	0.0990
P(PING)	0.1430	0.0440	0.0120	0.0040	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

P(DET BY TIME T | DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)

T(MIN)	10	20	30	40	50	60	70	80	90	100
10	0.5783	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.7952	0.5904	0.2152	0.0470	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	0.8795	0.7825	0.4702	0.2479	0.2476	0.0000	0.0000	0.0000	0.0000	0.0000
40	0.9438	0.8350	0.6490	0.5444	0.4905	0.3297	0.2117	0.2133	0.0000	0.0000
50	0.9673	0.8870	0.7801	0.6282	0.6286	0.5838	0.4453	0.4667	0.2783	0.2121
60	0.9833	0.9096	0.8411	0.7350	0.7381	0.7514	0.6423	0.6400	0.6087	0.3636
70	0.9900	0.9407	0.8742	0.8675	0.8429	0.8595	0.7445	0.7667	0.7565	0.6162
80	1.0000	0.9718	0.8974	0.9017	0.8952	0.8973	0.8321	0.8400	0.8087	0.7374
90	1.0000	0.9859	0.9404	0.9316	0.9048	0.9351	0.8832	0.9000	0.8783	0.8384
100	1.0000	0.9944	0.9570	0.9402	0.9333	0.9568	0.9197	0.9200	0.8870	0.8586
110	1.0000	0.9972	0.9702	0.9573	0.9571	0.9784	0.9343	0.9533	0.9043	0.9091
120	1.0000	0.9972	0.9766	0.9829	0.9667	0.9784	0.9635	0.9800	0.9391	0.9091
130	1.0000	1.0000	0.9803	0.9915	0.9810	1.0000	0.9927	0.9933	0.9826	0.9596
140	1.0000	1.0000	0.9808	1.0000	1.0000	1.0000	0.9927	1.0000	1.0000	0.9899
150	1.0000	1.0000	0.9868	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
160	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

P(DET BY DIP N | DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)

DIP #	10	20	30	40	50	60	70	80	90	100
1	0.6833	0.4294	0.2152	0.0556	0.0048	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.7831	0.5904	0.3775	0.1380	0.2476	0.2100	0.1606	0.2133	0.1652	0.1414
3	0.8213	0.7090	0.4702	0.3077	0.3667	0.3297	0.3066	0.3533	0.2783	0.2828
4	0.8795	0.7881	0.5662	0.4444	0.5048	0.5027	0.4453	0.4800	0.4783	0.3636
5	0.9398	0.8362	0.6490	0.5342	0.5610	0.5838	0.5182	0.5800	0.6087	0.5354
6	0.9438	0.8568	0.7165	0.6282	0.6476	0.6973	0.6423	0.6533	0.6261	0.6162
7	0.9673	0.8870	0.7801	0.6795	0.7381	0.7514	0.7372	0.7667	0.7565	0.7374
8	0.9673	0.8858	0.7960	0.7350	0.7667	0.8108	0.7445	0.7800	0.7565	0.7374
9	0.9673	0.9096	0.8510	0.8077	0.8429	0.8757	0.7956	0.8400	0.8174	0.7980
10	0.9833	0.9254	0.8742	0.8675	0.8905	0.8973	0.8394	0.9000	0.8783	0.8384
11	0.9900	0.9407	0.8874	0.8761	0.8952	0.8973	0.8394	0.9000	0.8783	0.8384
12	0.9900	0.9633	0.8974	0.9017	0.9048	0.9351	0.8905	0.9200	0.8870	0.8687
13	1.0000	0.9718	0.9106	0.9103	0.9048	0.9405	0.8978	0.9200	0.8870	0.8687
14	1.0000	0.9859	0.9404	0.9402	0.9333	0.9568	0.9343	0.9533	0.9043	0.9091
15	1.0000	0.9859	0.9404	0.9402	0.9333	0.9568	0.9343	0.9533	0.9043	0.9091
16	1.0000	0.9887	0.9570	0.9530	0.9571	0.9784	0.9635	0.9800	0.9391	0.9596
17	1.0000	0.9972	0.9603	0.9573	0.9571	0.9784	0.9635	0.9800	0.9391	0.9596
18	1.0000	0.9972	0.9702	0.9829	0.9667	0.9784	0.9927	0.9933	0.9826	0.9899
19	1.0000	0.9972	0.9702	0.9829	0.9667	0.9784	0.9927	0.9933	0.9826	0.9899
20	1.0000	0.9972	0.9763	0.9872	0.9810	1.0000	0.9927	1.0000	1.0000	1.0000
21	1.0000	1.0000	0.9801	0.9915	0.9857	1.0000	0.9927	1.0000	1.0000	1.0000
22	1.0000	1.0000	0.9803	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
23	1.0000	1.0000	0.9808	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
24	1.0000	1.0000	0.9868	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
25	1.0000	1.0000	0.9868	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
26	1.0000	1.0000	0.9901	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
27	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

TILT-ROTOR (JVX-ASW VARIANT)

SUBMARINE SPEED UNIFORM (5,20) KNOTS

ONE AIRCRAFT - ONE SUBMARINE

MAX DIP TIME 2 MIN   DISTANCE BETWEEN DIPS 3 NM

DISTANCE TO DATUM (NAUTICAL MILES)

	10	20	30	40	50	60	70	80	90	100
P(DET)	0.5910	0.4350	0.3390	0.2960	0.2640	0.2130	0.1950	0.1440	0.1290	0.1160
P(PING)	0.2050	0.0870	0.0420	0.0200	0.0120	0.0030	0.0020	0.0000	0.0000	0.0000

P(DET BY TIME T | DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)

T(MIN)	10	20	30	40	50	60	70	80	90	100
10	0.7310	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.9611	0.9103	0.7050	0.5608	0.1932	0.0516	0.0000	0.0000	0.0000	0.0000
30	0.9933	0.9977	0.9617	0.8277	0.7765	0.5515	0.4821	0.2847	0.2248	0.0000
40	1.0000	1.0000	0.9912	0.9764	0.9091	0.8732	0.7538	0.7153	0.5891	0.5431
50	1.0000	1.0000	0.9971	0.9966	0.9848	0.9577	0.9231	0.9167	0.8450	0.8362
60	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9397	0.9583	0.9690	0.9397
70	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9897	1.0000	0.9922	1.0000
80	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9922	1.0000
90	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

P(DET BY DIP N | DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)

DIP #	10	20	30	40	50	60	70	80	90	100
1	0.7310	0.6646	0.4661	0.3108	0.1932	0.0645	0.0308	0.0000	0.0000	0.0000
2	0.8680	0.7908	0.7050	0.5743	0.4811	0.3756	0.3282	0.2847	0.2791	0.3276
3	0.9611	0.9126	0.8319	0.7196	0.6477	0.5515	0.5282	0.5208	0.4651	0.5431
4	0.9780	0.9540	0.8820	0.8277	0.7992	0.7136	0.6154	0.6597	0.5891	0.6379
5	0.9956	0.9977	0.9617	0.9392	0.8902	0.8592	0.7538	0.8125	0.7597	0.8190
6	0.9983	1.0000	0.9735	0.9493	0.9091	0.8873	0.8308	0.8542	0.8450	0.8362
7	1.0000	1.0000	0.9912	0.9797	0.9773	0.9577	0.9231	0.9167	0.9457	0.9397
8	1.0000	1.0000	0.9912	0.9865	0.9848	0.9577	0.9282	0.9167	0.9457	0.9397
9	1.0000	1.0000	0.9941	0.9966	0.9962	0.9705	0.9744	0.9583	0.9690	0.9569
10	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9897	1.0000	0.9922	1.0000
11	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9897	1.0000	0.9922	1.0000
12	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9897	1.0000	0.9922	1.0000
13	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9922	1.0000
14	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

CV ASW HELICOPTER

SUBMARINE SPEED FIXED 5.0 KNOTS

TWO AIRCRAFT - ONE SUBMARINE

MAX DIP TIME 2 MIN   DISTANCE BETWEEN DIPS 5 NM

DISTANCE TO DATUM (NAUTICAL MILES)

	10	20	30	40	50	60	70	80	90	100
P(DET)	1.0000	1.0000	0.9640	0.8110	0.6600	0.6430	0.6110	0.6090	0.6460	0.6250
P(PING)	0.7170	0.4670	0.2320	0.0680	0.0200	0.0160	0.0300	0.0730	0.0720	0.0770

P(DET BY TIME T | DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)

T(MIN)	10	20	30	40	50	60	70	80	90	100
10	0.9990	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	1.0000	0.9980	0.9336	0.3403	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	1.0000	0.9980	0.9336	0.5586	0.2152	0.1851	0.1849	0.0000	0.0000	0.0000
40	1.0000	1.0000	0.9336	0.5635	0.2485	0.1851	0.2373	0.3025	0.2337	0.2000
50	1.0000	1.0000	0.9616	0.7472	0.5106	0.2862	0.3830	0.4463	0.3189	0.3584
60	1.0000	1.0000	0.9824	0.9248	0.6333	0.7247	0.6694	0.6116	0.4954	0.5200
70	1.0000	1.0000	0.9824	0.9248	0.8409	0.8818	0.8658	0.6909	0.6285	0.6784
80	1.0000	1.0000	0.9824	0.9248	0.8409	0.8834	0.8740	0.8909	0.8700	0.7392
90	1.0000	1.0000	0.9824	0.9248	0.8409	0.8834	0.8740	0.8909	0.8885	0.9088
100	1.0000	1.0000	0.9824	0.9237	0.8485	0.8834	0.8740	0.8909	0.8885	0.9088
110	1.0000	1.0000	0.9824	0.9297	0.8500	0.8896	0.8756	0.8909	0.8835	0.9088
120	1.0000	1.0000	0.9533	0.9420	0.8924	0.9285	0.8789	0.9124	0.9288	0.9088
130	1.0000	1.0000	0.9969	0.9679	0.9394	0.9580	0.9362	0.9537	0.9628	0.9712
140	1.0000	1.0000	0.9990	0.9951	0.9879	0.9829	0.9935	0.9537	0.9644	1.0000
150	1.0000	1.0000	1.0000	1.0000	0.9939	0.9876	1.0000	1.0000	1.0000	1.0000
160	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

P(DET BY DIP N | DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)

DIP #	10	20	30	40	50	60	70	80	90	100
1	1.0000	0.9980	0.9336	0.5586	0.2152	0.1851	0.2373	0.2676	0.2337	0.2320
2	1.0000	0.9980	0.9336	0.5586	0.2152	0.1851	0.2373	0.3341	0.3189	0.3584
3	1.0000	0.9980	0.9336	0.5586	0.2152	0.1851	0.2373	0.3041	0.3189	0.3584
4	1.0000	0.9980	0.9336	0.5635	0.2773	0.2862	0.3830	0.4661	0.4954	0.5200
5	1.0000	0.9980	0.9336	0.5635	0.2773	0.2862	0.3830	0.4661	0.4954	0.5232
6	1.0000	1.0000	0.9512	0.7472	0.5318	0.6267	0.6694	0.6876	0.6285	0.6734
7	1.0000	1.0000	0.9616	0.8311	0.6803	0.7294	0.7103	0.6909	0.6285	0.6784
8	1.0000	1.0000	0.9824	0.9248	0.8409	0.8818	0.8658	0.8132	0.7183	0.7392
9	1.0000	1.0000	0.9824	0.9248	0.8409	0.8834	0.8740	0.8909	0.8885	0.9088
10	1.0000	1.0000	0.9824	0.9248	0.8409	0.8834	0.8740	0.8909	0.8885	0.9088
11	1.0000	1.0000	0.9824	0.9248	0.8409	0.8834	0.8740	0.8909	0.8835	0.9088
12	1.0000	1.0000	0.9824	0.9248	0.8409	0.8834	0.8740	0.8909	0.8885	0.9088
13	1.0000	1.0000	0.9824	0.9248	0.8409	0.8834	0.8740	0.8909	0.8885	0.9088
14	1.0000	1.0000	0.9824	0.9248	0.8409	0.8834	0.8740	0.8909	0.8885	0.9088
15	1.0000	1.0000	0.9824	0.9297	0.8500	0.8896	0.8756	0.8909	0.8885	0.9088
16	1.0000	1.0000	0.9824	0.9297	0.8500	0.8896	0.8789	0.9124	0.9268	0.9712
17	1.0000	1.0000	0.9824	0.9297	0.8500	0.8896	0.8789	0.9124	0.9288	0.9712
18	1.0000	1.0000	0.9824	0.9420	0.8924	0.9316	0.9362	0.9537	0.9644	1.0000
19	1.0000	1.0000	0.9844	0.9420	0.8924	0.9316	0.9362	0.9537	0.9644	1.0000
20	1.0000	1.0000	0.9958	0.9679	0.9394	0.9596	0.9556	0.9587	0.9659	1.0000
21	1.0000	1.0000	0.9938	0.9679	0.9439	0.9751	0.9935	0.9983	1.0000	1.0000
22	1.0000	1.0000	0.9990	0.9951	0.9879	0.9876	1.0000	1.0000	1.0000	1.0000
23	1.0000	1.0000	0.9990	0.9951	0.9879	0.9876	1.0000	1.0000	1.0000	1.0000
24	1.0000	1.0000	1.0000	0.9988	0.9939	1.0000	1.0000	1.0000	1.0000	1.0000
25	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

TILT-ROTOR (JVX-ASW VARIANT)

SUBMARINE SPEED FIXED 5.0 KNOTS

TWO AIRCRAFT - ONE SUBMARINE

MAX DIP TIME 2 MIN   DISTANCE BETWEEN DIPS 5 NM

DISTANCE TO DATUM (NAUTICAL MILES)

	10	20	30	40	50	60	70	80	90	100
P(DET)	1.0000	1.0000	1.0000	0.9890	0.9250	0.8070	0.7130	0.6600	0.6400	0.6370
P(PING)	0.8010	0.6580	0.4590	0.3250	0.1670	0.0900	0.0280	0.0140	0.0110	0.0260

P(DET BY TIME T | DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)

T(MIN)	10	20	30	40	50	60	70	80	90	100
10	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	1.0000	1.0000	0.9930	0.9808	0.8746	0.4734	0.0000	0.0000	0.0000	0.0000
30	1.0000	1.0000	0.9980	0.9808	0.8746	0.6419	0.3450	0.1773	0.1422	0.1978
40	1.0000	1.0000	0.9990	0.9808	0.8746	0.6481	0.3731	0.1939	0.1422	0.1978
50	1.0000	1.0000	0.9930	0.9899	0.9470	0.7782	0.5283	0.2273	0.2375	0.3171
60	1.0000	1.0000	1.0000	0.9970	0.9327	0.9418	0.8668	0.6394	0.7062	0.6782
70	1.0000	1.0000	1.0000	0.9970	0.9827	0.9418	0.8836	0.8455	0.8672	0.8791
80	1.0000	1.0000	1.0000	0.9970	0.9327	0.9413	0.8836	0.3455	0.6672	0.8870
90	1.0000	1.0000	1.0000	0.9970	0.9827	0.9418	0.8836	0.8455	0.8672	0.8870
100	1.0000	1.0000	1.0000	0.9970	0.9827	0.9442	0.8946	0.8301	0.8672	0.8870
110	1.0000	1.0000	1.0000	0.9970	0.9827	0.9442	0.8943	0.8591	0.8797	0.8917
120	1.0000	1.0000	1.0000	0.9990	0.9903	0.9542	0.9158	0.9000	0.9406	0.9356
130	1.0000	1.0000	1.0000	0.9990	0.9957	0.9777	0.9579	0.9333	0.9578	0.9670
140	1.0000	1.0000	1.0000	0.9990	0.9968	0.9563	0.9888	0.9697	0.9844	0.9812
150	1.0000	1.0000	1.0000	0.9990	0.9978	1.0000	0.9972	0.9918	0.9891	0.9922
160	1.0000	1.0000	1.0000	1.0000	0.9978	1.0000	1.0000	1.0000	1.0000	1.0000
170	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

P(DET [illegible]P # | DETECTION)

DISTANCE [illegible] (NAUTICAL MILES)

DIP #	10	20	30		50	60	70	80	90	100
1	1.0000	1.0000	0.9980	0.98[illegible]	0.8746	0.6419	0.3450	0.1773	0.1422	0.1978
2	1.0000	1.0000	0.9980	0.9803	0.8746	0.6419	0.3450	0.1773	0.1422	0.1978
3	1.0000	1.0000	0.9980	0.9308	0.8746	0.6419	0.3450	0.1773	0.1422	0.1973
4	1.0000	1.0000	0.9980	0.9808	0.8746	0.6481	0.3731	0.2273	0.2375	0.3171
5	1.0000	1.0000	0.9980	0.9808	0.8746	0.6481	0.3731	0.2273	0.2375	0.3171
6	1.0000	1.0000	0.9990	0.9858	0.7189	0.7782	0.6297	0.5439	0.5969	0.6531
7	1.0000	1.0000	0.9990	0.9899	0.9503	0.8327	0.7391	0.6394	0.7062	0.7378
8	1.0000	1.0000	1.0000	0.9970	0.9827	0.9413	0.8830	0.8455	0.8672	0.8791
9	1.0000	1.0000	1.0000	0.9970	0.9827	0.9418	0.8836	0.8455	0.8672	0.8870
10	1.0000	1.0000	1.0000	0.9970	0.9827	0.9418	0.8836	0.8455	0.8672	0.8870
11	1.0000	1.0000	1.0000	0.9970	0.9827	0.9418	0.8836	0.8455	0.8672	0.8870
12	1.0000	1.0000	1.0000	0.9970	0.9827	0.9418	0.8836	0.8455	0.8672	0.8870
13	1.0000	1.0000	1.0000	0.9970	0.9827	0.9418	0.8836	0.8455	0.8672	0.8870
14	1.0000	1.0000	1.0000	0.9970	0.9827	0.9418	0.8836	0.8455	0.8672	0.8870
15	1.0000	1.0000	1.0000	0.9970	0.9827	0.9442	0.8948	0.8591	0.8797	0.8917
16	1.0000	1.0000	1.0000	0.9970	0.9827	0.9442	0.8948	0.8591	0.3797	0.8917
17	1.0000	1.0000	1.0000	0.9970	0.9827	0.9442	0.8948	0.8591	0.8797	0.8917
18	1.0000	1.0000	1.0000	0.9970	0.9827	0.9542	0.9158	0.9000	0.9422	0.9529
19	1.0000	1.0000	1.0000	0.9980	0.9858	0.9542	0.9158	0.9000	0.9422	0.9529
20	1.0000	1.0000	1.0000	0.9990	0.9903	0.9777	0.9579	0.9333	0.9578	0.9702
21	1.0000	1.0000	1.0000	0.9990	0.9903	0.9777	0.9579	0.9364	0.9641	0.9812
22	1.0000	1.0000	1.0000	0.9990	0.9968	0.9563	0.9888	0.9697	0.9844	0.9922
23	1.0000	1.0000	1.0000	0.9990	0.9968	0.9563	0.9888	0.9697	0.9844	0.9922
24	1.0000	1.0000	1.0000	0.9990	0.9973	0.9588	0.9972	0.9818	0.9906	1.0000
25	1.0000	1.0000	1.0000	0.9990	0.9978	1.0000	1.0000	1.0000	1.0000	1.0000
26	1.0000	1.0000	1.0000	0.9990	0.9978	1.0000	1.0000	1.0000	1.0000	1.0000
27	1.0000	1.0000	1.0000	0.9990	0.9978	1.0000	1.0000	1.0000	1.0000	1.0000
28	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

CV ASW HELICOPTER

SUBMARINE SPEED FIXED 10.0 KNOTS

ONE AIRCRAFT - ONE SUBMARINE

MAX DIP TIME 2 MIN   DISTANCE BETWEEN DIPS 3 NM

DISTANCE TO DATUM (NAUTICAL MILES)

	10	20	30	40	50	60	70	80	90	100
P(DET)	0.7140	0.4740	0.3340	0.2100	0.1290	0.0320	0.0000	0.0000	0.0000	0.0000
P(PING)	0.0730	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

P(DET BY TIME T | DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)

T(MIN)	10	20	30	40	50	60	70	80	90	100
10	0.4463	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.8595	0.4093	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	0.9972	0.9705	0.8263	0.9476	0.3178	0.0000	0.0000	0.0000	0.0000	0.0000
40	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000

P(DET BY DIP N | DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)

DIP #	10	20	30	40	50	60	70	80	90	100
1	0.6443	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.7913	0.4093	0.4760	0.5286	0.3178	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.8595	0.5886	0.8114	0.9476	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000
4	0.9216	0.7764	0.8263	0.9476	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000
5	0.9972	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000
6	0.9972	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000
7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000

TILT-ROTOR (JVX-ASW VARIANT)

SUBMARINE SPEED FIXED 10.0 KNOTS

ONE AIRCRAFT - ONE SUBMARINE

MAX DIP TIME 2 MIN   DISTANCE BETWEEN DIPS 5 NM

DISTANCE TO DATUM (NAUTICAL MILES)										
	10	20	30	40	50	60	70	80	90	100
P(DET)	0.8730	0.5370	0.3390	0.3950	0.3700	0.3320	0.3120	0.2780	0.2490	0.2040
P(PING)	0.1930	0.0390	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

P(DET BY TIME T | DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)										
T(MIN)	10	20	30	40	50	60	70	80	90	100
10	0.9141	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.9141	0.4358	0.0059	0.0025	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	0.9404	0.5903	0.2950	0.1139	0.1919	0.2552	0.3814	0.3633	0.0000	0.0000
40	0.9576	0.7188	0.4556	0.5392	0.6243	0.5542	0.6218	0.6223	0.6867	0.7647
50	0.9725	0.8082	0.6460	0.7038	0.7568	0.7410	0.8814	0.8705	0.9157	0.9069
60	0.9753	0.8715	0.6460	0.7038	0.7649	0.7522	0.8814	0.8705	0.9157	0.9314
70	0.9931	0.9516	0.8142	0.8253	0.8838	0.9247	0.9583	0.8705	0.9157	0.9314
80	1.0000	1.0000	1.0000	0.9899	0.9135	0.9247	0.9712	1.0000	1.0000	1.0000
90	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

P(DET BY DIP N | DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)										
DIP #	10	20	30	40	50	60	70	80	90	100
1	0.9141	0.4246	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.9141	0.4358	0.0177	0.1139	0.1919	0.2552	0.3814	0.3777	0.3695	0.4118
3	0.9141	0.4358	0.0177	0.1139	0.1919	0.2552	0.4712	0.5683	0.6867	0.7745
4	0.9381	0.5903	0.3038	0.3620	0.4378	0.5542	0.6218	0.6475	0.6908	0.7745
5	0.9433	0.6778	0.4484	0.5392	0.6297	0.7410	0.8814	0.8705	0.9157	0.9314
6	0.9576	0.7188	0.5015	0.5494	0.6297	0.7410	0.8814	0.8705	0.9157	0.9314
7	0.9725	0.8082	0.6460	0.7038	0.7649	0.7522	0.8814	0.8705	0.9157	0.9314
8	0.9725	0.8082	0.6460	0.7038	0.7649	0.7522	0.8814	0.8705	0.9157	0.9314
9	0.9725	0.8082	0.6460	0.7038	0.7649	0.7522	0.8814	0.8705	0.9157	0.9314
10	0.9753	0.8752	0.7670	0.8228	0.8838	0.9247	0.9712	1.0000	1.0000	1.0000
11	0.9851	0.8576	0.8142	0.8253	0.8838	0.9247	0.9712	1.0000	1.0000	1.0000
12	0.9931	0.9590	0.9174	0.9013	0.9135	0.9247	0.9712	1.0000	1.0000	1.0000
13	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

CV ASW HELICOPTER

SUBMARINE SPEED FIXED 15.0 KNOTS

TWO AIRCRAFT - ONE SUBMARINE

MAX DIP TIME 2 MIN   DISTANCE BETWEEN DIPS 4 NM

DISTANCE TO DATUM (NAUTICAL MILES)

	10	20	30	40	50	60	70	80	90	100
P(DET)	0.5350	0.4060	0.3060	0.1490	0.1340	0.0750	0.0190	0.0000	0.0000	0.0000
P(PING)	0.1010	0.1050	0.0320	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

P(DET BY TIME T | DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)

T(MIN)	10	20	30	40	50	60	70	80	90	100
10	0.3159	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.8056	0.7217	0.2974	0.0067	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	0.9941	0.9926	0.9248	0.8926	0.5000	0.0000	0.0000	0.0000	0.0000	0.0000
40	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.8947	0.0000	0.0000	0.0000
50	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000

P(DET BY DIP N | DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)

DIP #	10	20	30	40	50	60	70	80	90	100
1	0.3583	0.4015	0.2974	0.0067	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.6336	0.7217	0.6667	0.5570	0.5000	0.2933	0.0000	0.0000	0.0000	0.0000
3	0.8283	0.9187	0.9248	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000
4	0.8673	0.9926	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000
5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000

TILT-ROTOR (JVX-ASW VARIANT)

SUBMARINE SPEED FIXED 15.0 KNOTS

TWO AIRCRAFT - ONE SUBMARINE

MAX DIP TIME 2 MIN   DISTANCE BETWEEN DIPS 4 NM

DISTANCE TO DATUM (NAUTICAL MILES)

	10	20	30	40	50	60	70	80	90	100
P(DET)	0.5530	0.4750	0.4110	0.3590	0.2730	0.1510	0.1680	0.1390	0.0970	0.0410
P(PING)	0.0830	0.1100	0.0990	0.0540	0.0150	0.0000	0.0000	0.0000	0.0000	0.0000

P(DET BY TIME T | DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)

T(MIN)	10	20	30	40	50	60	70	80	90	100
10	0.3600	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.7273	0.8384	0.7032	0.6267	0.1832	0.0066	0.0000	0.0000	0.0000	0.0000
30	1.0000	0.9958	0.9708	0.9972	0.9634	0.9536	0.5774	0.5468	0.0000	0.0000
40	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

P(DET BY DIP N | DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)

DIP #	10	20	30	40	50	60	70	80	90	100
1	0.3600	0.3789	0.3723	0.3677	0.1832	0.0066	0.0000	0.0000	0.0000	0.0000
2	0.5855	0.6568	0.7032	0.6769	0.6447	0.5828	0.5774	0.5468	0.3299	0.0244
3	0.7273	0.8674	0.9294	0.8997	0.9634	0.9534	1.0000	1.0000	1.0000	1.0000
4	0.7891	0.8989	0.9708	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

CV ASW HELICOPTER

SUBMARINE SPEED FIXED 20.0 KNOTS

TWO AIRCRAFT - ONE SUBMARINE

MAX DIP TIME 2 MIN   DISTANCE BETWEEN DIPS 5 NM

DISTANCE TO DATUM (NAUTICAL MILES)

	10	20	30	40	50	60	70	80	90	100
P(DET)	0.3380	0.2800	0.1040	0.1140	0.0580	0.0040	0.0000	0.0000	0.0000	0.0000
P(PING)	0.0860	0.0810	0.0020	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

P(DET BY TIME T | DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)

T(MIN)	10	20	30	40	50	60	70	80	90	100
10	0.3817	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.8876	0.7564	0.0577	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	1.0000	1.0000	1.0000	0.7456	0.2414	0.0000	0.0000	0.0000	0.0000	0.0000
40	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000

P(DET BY DIP N | DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)

DIP #	10	20	30	40	50	60	70	80	90	100
1	0.4231	0.4766	0.0577	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.7308	0.8036	0.7212	0.4737	0.2414	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.9435	0.9964	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000
4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000

TILT-ROTOR (JVX-ASW VARIANT)

SUBMARINE SPEED FIXED 20.0 KNOTS

ONE AIRCRAFT - ONE SUBMARINE

MAX DIP TIME 2 MIN   DISTANCE BETWEEN DIPS 5 NM

DISTANCE TO DATUM (NAUTICAL MILES)

	10	20	30	40	50	60	70	80	90	100
P(DET)	0.1770	0.1650	0.1360	0.0290	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
P(PING)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

P(DET BY TIME T \| DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)

T(MIN)	10	20	30	40	50	60	70	80	90	100
10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.9774	0.5858	0.5882	0.1034	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

P(DET BY DIP N \| DETECTION)

DISTANCE TO DATUM (NAUTICAL MILES)

DIP #	10	20	30	40	50	60	70	80	90	100
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.5476	0.5858	0.5882	0.3103	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

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